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THE UNIVERSITY OF ALBERTA

The Quaternary geology of the Grande Prairie area, Alberta

by

David G.E. Liverman

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

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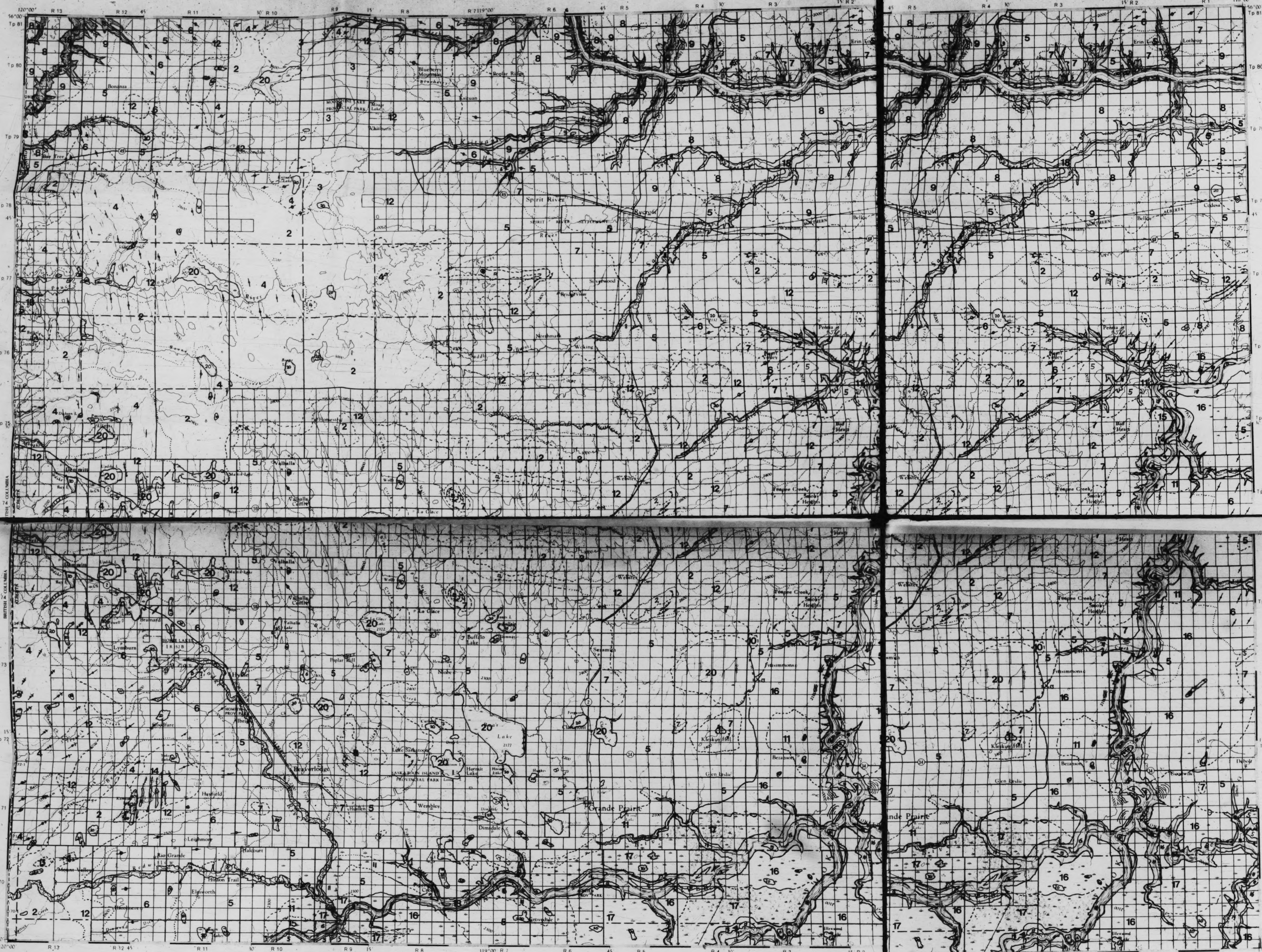
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BRITISH COLUMBIA
ALBERTA
Bonanza
Blueberry Mountain
Poplar Ridge
Moonshine Lake Provincial Park
Whitburn
Spirit River
Spirit River Settlement
Rycroft
Wanham
Belloy
Codesa
Erin Lodge
Lothrop
Silverwood
Bridgeview
Northmark
Woking
Gundy
Peoria
Bad Heart
Demmitt
Valhalla
Valhalla Centre
Webster
Teepee Creek
Smoky Heights
La Glace
Lymburn
Hythe
Buffalo Lake
Niobe
Poplar Hill
Sexsmith
Fitzsimmons
Kleskun Hill
Bezanson
Glen Leslie
Debolt
Goodwin
Beaverlodge
Saskatoon Lake
Saskatoon Island Provincial Park
Hermit Lake
Clairmont
Wembley
Hayfield
Grande Prairie
Dimsdale
Leighmore
Halcourt
Rio Grande
Hinton Trail
Elmworth
Grovedale

Surficial Geology, Grande Prairie Area

This map represents an interpretation of the surficial geology of the Grande Prairie (83M) map area.

Legend

Unit #	Map symbol	Description	% map area	Air photo pattern	topography	slope angles	material properties	material origin
1	rRm+rRr	bedrock	<1	light, variable tones	varied, scarp and dip pattern, up to 100 m relief	gentle-steep	mainly sandstone shale, coal	bedrock
2	dDv rRm+rRr	diamicton veneer over bedrock	15%	light to dark variable tones	as above	gentle-moderate	sandy diamicton over bedrock	till (ablation?)
3	dMh	hummocky	2%	dark mottled tones	irregular hummocks	moderate	diamicton	melt-out till
4	dMr/dMd	ridged diamicton	10%	parallel lineations, dark-light tones	elongate ridges, 5-30 m relief	gentle	diamicton	till, probably melt out till at surface
5	fLp	silt and clay plain	20%	dark even tones	little relief	flat	silt and clay, few coarse clasts	glaciolacustrine
6	fLl+fLv dMr+dMp	lineated silt and clay veneer of silt over ridged diamicton	5%	parallel lineations, dark even tones	rolling to flat	gentle	silt and clay, some coarse clasts	glaciolacustrine drape over diamict, bedrock lineation
7	fLm dMm+rRm	veneer of clay & silt over diamicton & bedrock.	5%	mottled dark to light tones	rolling	moderate-steep	silt and clay/ diamicton & bedrock	glaciolacustrine drape over thin till & bedrock
8	fLh	hummocky silt and clay	5%	regular mottles, light and dark tones	hummocks, 2-8m relief	gentle-moderate	silt & clay	deformed glaciolacustrine
9	fLr	rolling silt and clay	5%	as above	low hummocks 0-2 m relief	gentle-flat	silt and clay	as above
10.	fLp rFr	concentric lineated silt and clay	[illegible]	even tones, concentric lineation	low	gentle	silt and clay over bedrock	glaciolacustrine [illegible] ice thrust bedrock
11	[illegible]	pitted silt and clay	5%	even tones with irregular pits	low relief	flat - gentle	silt and clay with minor organics	glaciolacustrine silt pitted by wind
12	fLv various	silt and clay veneer	5%	dark mottled tones	varied, conforms to that of underlying material	varied mainly gentle	silt/ clay with many stones	ice proximal glaciolacustrine and strandlines
13	fLv gGr	ridged sand & gravel	1%	light tones	low ridge, 2-5 m high	gentle	poorly sorted sand & gravel	esker or kame
14	gGm + gGc dMr	complex sand and gravel	2%	light tone, complex lineation pattern	rolling, channeled low relief	gentle	poorly sorted sand & gravel	glaciofluvial outwash
15	gFt+sFt	terraced sand and gravel	1%	light tones, adjacent to modern rivers	flat, channeled	flat	gravel and sand	post-glacial terraces
16	sAh+sAv fLp	hummocks and veneer of sand	7%	light mottled tones	low hummocks	gentle	fine sand and silt over silt and clay	aeolian dome dunes and sand sheet
17	sAr fLp+gFt	ridged sand over silt and gravels	7%	light toned U shaped lineation"	sharp crested elongate ridges	moderate steep	medium sand over gravel, silt and clay	parabolic dunes
18	dCx+rCx	colluvium	<1%	semi-circular lineation, dark, uneven tones	steep irregular slopes	steep	bedrock & diamicton	bedrock, till & glacial lake clay re-sedimented by

		gravel		to modern rivers				
16	$\frac{\text{sAh+sAv}}{\text{fLp}}$	hummocks sand veneer of sand	7%	light mottled tones	low hummocks	gentle	fine sand and silt over silt and clay	aeolian dome dunes and sand sheet
17	$\frac{\text{sAr}}{\text{fLp+gFt}}$	ridged sand over silt and gravels	7%	light toned U shaped lineation	sharp crested elongate ridges	moderate -steep	medium sand over gravel, silt and clay	parabolic dunes
18	dCx+rCx	colluvium	< 1%	semi-circular lineation, dark uneven tones	steep irregular slopes	steep	bedrock & diamicton	bedrock, till & glacial lake clay re-sedimented by rotational slump & debris flow
19	gFc+sFp	modern alluvium	2%	light tones at base of river valleys	flat to terraced	gentle-flat	gravel, sand and minor silt	modern alluvium
20	pOp+cLp	organic deposits	3%	even dark tones	gentle depressions	flat	peat and clay	modern lacustrine & swamp deposits

—— - - ····· unit boundary (defined, approximate, assumed)

↗ oriented glacial landform (drumlin, flute, gouge, direction known)

/ oriented glacial landform (drumlin, flute, gouge, direction unknown)

/ lineation (origin unknown)

large meltwater channel

‡ minor meltwater channel

strandline feature (depositional)

strandline (erosional)

slump scars

scarp

Units are designated on the map by unit number

FIGURE 7 - SURFICIAL GEOLOGY OF THE GRANDE PRAIRIE MAP SHEET

To accompany "Quaternary Geology of the Grande Prairie area", Ph.D. thesis by

David Liverman, Department of Geology, University of Alberta

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Quaternary geology of the Grande Prairie area, Alberta" submitted by David G.E. Liverman in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Geology.

Dr. N.W. Rutter (Supervisor)

Dr. J..T. Teller (External Examiner)

Dr. I. Campbell

Dr. C.R. Stelck

Dr. J.F. Lerbekmo

Date May 3, 1989

ABSTRACT

The Grande Prairie map sheet (NTS 83M) covers an area of approximately 14,000 square kilometres of north-western Alberta. A surficial geology map is presented, with 20 map units designated. The oldest unconsolidated sediments recognised in the area consist of Middle Wisconsinan sands and gravels, pre-dating Laurentide glaciation of the area. Glaciation from the Rocky Mountains affected the southwest part of the map sheet, either early in the Late Wisconsinan, or prior to the Late Wisconsinan. Laurentide ice advanced over the entire area in the Late Wisconsinan. During this advance, isolated deposition of inter-stratified sand, gravel, and diamicton took place in pro-glacial lakes formed as regional drainage was dammed. The extent of Laurentide ice was limited by topography rather than coalescence with ice from the Rocky Mountains, and it deposited a blanket of diamicton. Most glacigenic diamicton was deposited as basal melt-out till, and subsequently remobilised; or as sub-aquatic debris flow into pro-glacial lakes formed in retreat. Four stages of lake development are recognised in the area. Stage 1 consisted of a series of minor lakes formed early in retreat, and dominated by ice-proximal sedimentation of diamicton. Stage 2 is related to a series of strandlines at 810 and 840 m.a.s.l. Sedimentation at this stage was dominated by turbidity currents; debris flows derived from the ice margin, and resedimentation of diamicton on the lake margins. Stage 3 is related to strandlines between 655 and 730 m.a.s.l. In topographic lows, ice proximal sedimentation is followed by sedimentation dominated by non-glacial inflow from re-established drainage to the west. Away from topographic lows, little sedimentation took place. The final stage of lake development only affected low lying areas of the Peace River Valley, and resulted in the deposition of pro-delta sediments from the re-established Peace River. Following final drainage of pro-glacial lakes prior to 11,000 B.P., entrenchment of major rivers and terrace development took place, associated with aeolian sedimentation and the formation of extensive fields of parabolic and dome dunes.

Acknowledgements.

A Ph.D thesis requires assistance and support from many individuals and organizations. Firstly I am indebted to previous workers in northwestern Alberta, and northeastern British Columbia. Although I may not have agreed with all of their conclusions, I was constantly impressed by the accuracy of their observations. Field work was greatly assisted by the willingness of the farmers of the Grande Praire area in allowing access to their property.

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CHAPTER 1: INTRODUCTION

> *"....till catching a glimpse of a still more open country to the northward we turn in that direction and emerge on a valley with gently sloping sides, one to two miles wide and chiefly prairie...This is the first prairie country we have seen and contrasts very pleasantly with the dense forests through which we for the most part we have heretofore been groping our way. The grass is in some places as high as the horses' bellies and is already ripe and turning brown at the tops. The hillsides are gay with summer flowers..."*
>
> G.M Dawson (1881) in the area of Pouce Coupe,

The Grande Prairie 1:250,000 map sheet (NTS 83M) is located in northwestern Alberta, Canada, and covers an area of approximately 14,000 km^2 (Figure 1). The eastern boundary is marked by longitude 118° W and the western (which is also the boundary between Alberta and British Columbia) by longitude 120^0 W. The north and south boundaries are latitudes 56° N and 55° N respectively. The primary objectives of this study are to describe of the nature and distribution of surficial deposits and to investigate the Quaternary geology of the area covered by the 83M sheet.

Such a study is important because, firstly, this map sheet is located in a position such that it is thought that ice from both the Rocky Mountains and the Laurentide ice sheet deposited sediments there during the Quaternary (Mathews 1980; Rutter 1981, 1984). The relationship between Laurentide and mountain ice is controversial, and of great interest because of the implications of the presence or absence of an ice-free corridor between the ice sheets. It is suggested that an ice free corridor may have allowed migration of man and other species to North America during the late Wisconsinan (Johnston 1933; Martin 1973; Reeves 1973). In northern Alberta, the extent and timing of glacial advances from east and west are poorly understood and thus further study is

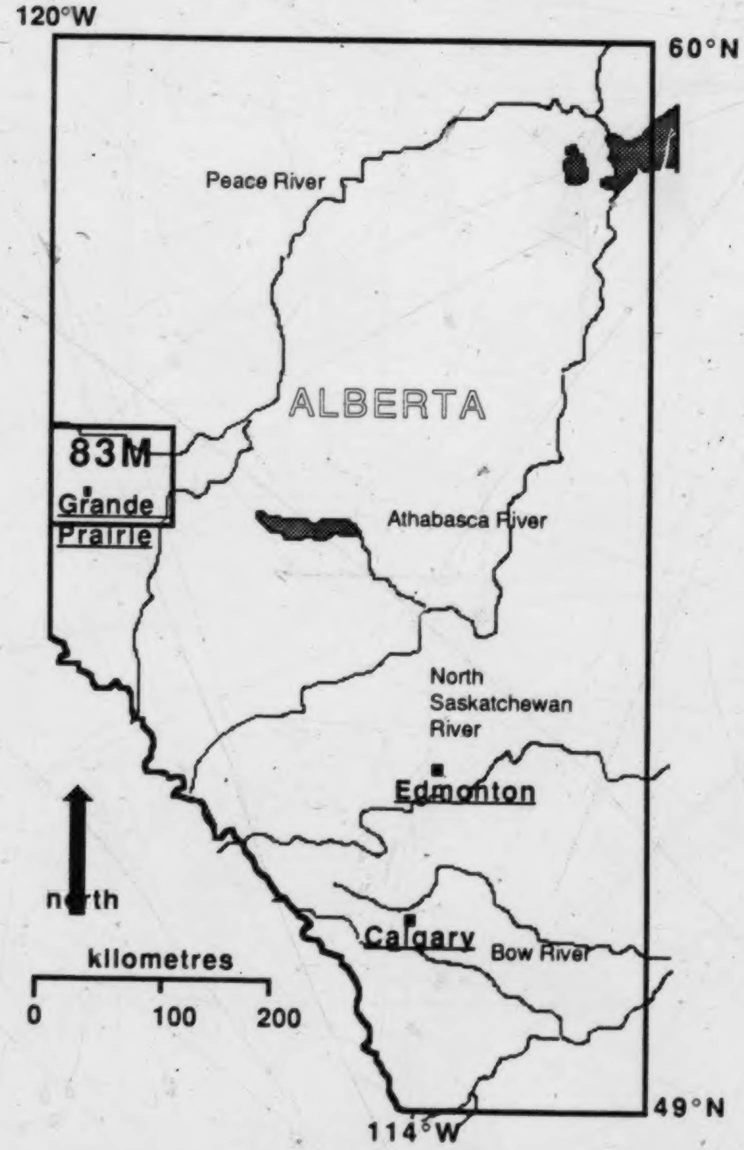

120°W
60°N
Peace River
ALBERTA
83M
Grande Prairie
Athabasca River
North Saskatchewan River
Edmonton
north
kilometres
0
100
200
Calgary
Bow River
49°N
114°W

Figure 1:- Location of study area

needed of critical areas which lay at the margins of both ice sheets.

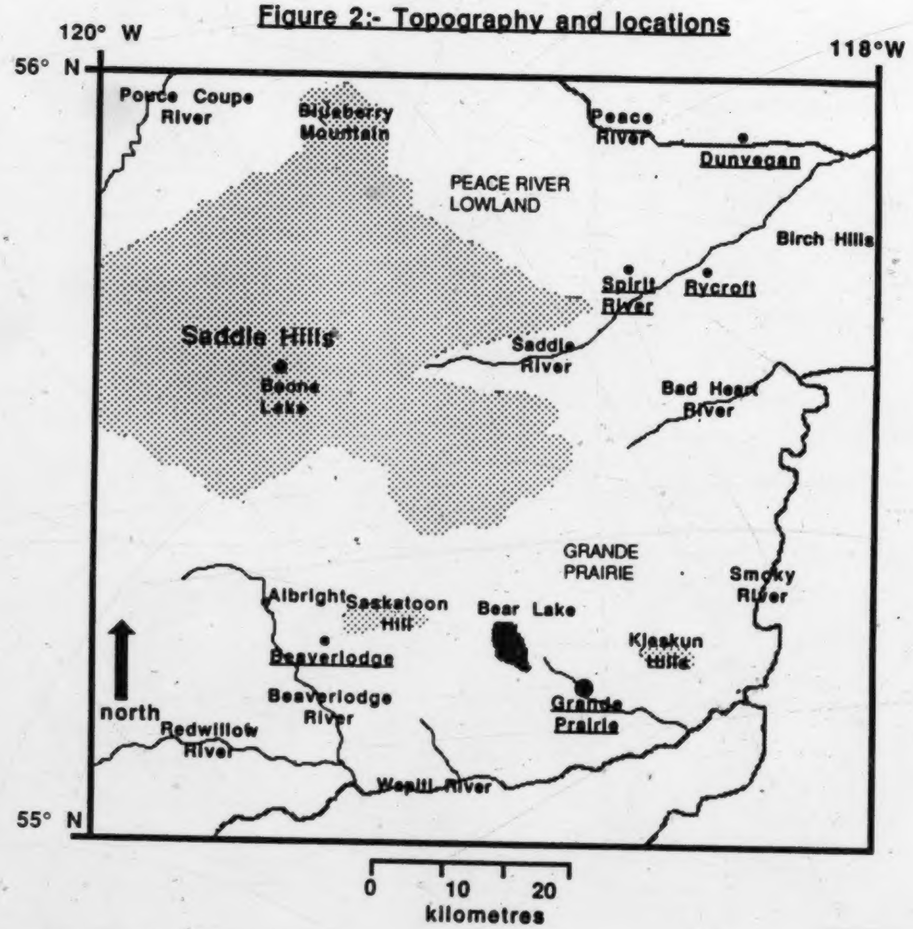
A second justification for the study is the lack of a detailed surficial geology map of the area. The Grande Prairie region is of great economic importance in the development of northwestern Alberta, and an understanding of the properties and distribution of surficial deposits is essential. This may assist in location of sand and gravel deposits; slope stability studies for construction; pipeline location and construction; and understanding of soil development and distribution.

Geography and history

The region is part of the Western Canadian Interior Plains, lying between the Cordillera to the west and the Canadian Shield to the east (Bostock 1970). In the Grande Prairie area the plain lies at an altitude of 600 to 750 metres and is dissected by three major rivers: the Peace, Smoky and Wapiti (Figure 2). The Wapiti is a tributary of the Smoky, joining it east of Grande Prairie,10 km south of the Highway 34 bridge. The Smoky River joins the Peace at the town of Peace River, 150 km northeast of Grande Prairie. These valleys lie between 180 and 300 metres below the prairie surface.

The Grande Prairie 1:250,000 map sheet (83M) is divided into three broad areas (Figure 2). To the south is the agricultural area of Grande Prairie itself, rising gently from the Wapiti and Smoky valleys. There are two noteworthy high points, Saskatoon and Kleskun Hills (with altitudes of 840 and 750 metres respectively), and many shallow lakes, the largest of which is Bear Lake. This area has many settlements, with the city of Grande Prairie, and the towns of Sexsmith, Beaverlodge, Spirit River, Rycroft, Hythe and Wembley being the main centres. The central portion of the map sheet is dominated by the Saddle .

Figure 2:- Topography and locations


120° W
118°W
56° N
55° N
Pouce Coupe River
Blueberry Mountain
Peace River
Dunvegan
PEACE RIVER LOWLAND
Birch Hills
Spirit River
Rycroft
Saddle Hills
Saddle River
Boone Lake
Bad Heart River
GRANDE PRAIRIE
Smoky River
Albright
Saskatoon Hill
Bear Lake
Kleskun Hills
Beaverlodge
Beaverlodge River
Grande Prairie
north
Redwillow River
Wapiti River
0
10
20
kilometres

Hills, rising to 1000 m, densely wooded, with little agriculture and poor access North of this lies the agricultural Peace River lowland with rolling gentle topography falling gradually from the Saddle Hills to the edge of the Peace Valley. Blueberry Hill is a northwards extension of the Saddle Hills, and separates the Pouce Coupe prairie with the towns of Dawson Creek and Pouce Coupe from the Spirit River prairie with the villages of Spirit River and Rycroft. The Birch Hills rise to an altitiude of 720 metres to the east of Rycroft.

Comparatively little is known regarding prehistoric occupation of the area. A Clovis point is reported to have been found in the region of the Birch Hills (M Wright, Alberta Archaeological Survey, personal communication 1987). Fladmark (1981) reports surface occurrences of fluted points in the Peace River area. Extensive investigations to the northwest of the map area at Charlie Lake Cave have located a stratified archaeological site, with associated faunal remains. The lowest level, containing lithic artifacts and bison bones with evidence of butchering, has been dated at a maximum of 10,770±120 B.P.(SFU 454; Fladmark *et al.* 1988).

Prior to European influence the area was inhabited by people of the Dene and Cree nations. In the past a major trade and migration route passed south of Grande Prairie, and the prairie regions were productive hunting grounds and favoured berry harvesting sites (Dawson 1881). The first Europeans arrived by way of the major rivers at the end of the 18th century. The route was circuitous, *via* Methy Portage (near modern Fort McMurray), the Athabasca River and up the Peace from Lake Athabasca. In 1797, John Finlay established the first settlement in the Upper Peace in the vicinity of Fort St. John. Another major settlement in the study area was at Dunvegan, where a fort and trading post was first established in 1805 by A. McLeod of the North West Company. The fort was followed by both Protestant and Catholic missions, and remained a centre of commerce and activity for 100 years. Following the routing of the railway bridge through the town of Peace River in the early 20th century, the settlement was virtually abandoned and is now an historic site, with the Catholic church and mission restored.

Settlement took the form of trading posts and missions until the early years of this century when the agricultural potential of the area began to be recognized. Early settlers came by way of the Edson Trail, when travel from the railhead at Edson could take up to three months due to appalling conditions on the trail. Grande Prairie itself did not become established as a settlement until 1912, and most other towns were founded around this time. The Edson Trail was used for only four years, between 1911 and 1915, but provided the first impetus for development of the area. A second major development was the construction of the Northern Alberta Railway in the years following the First World War. Construction of the Alaska Highway during the Second World War provided an economic boost, with Dawson Creek being the focus of development, and the highway has continued to carry traffic northwards through the Grande Prairie area. In 1952 the population of Grande Prairie was approximately 5000; today it is over 25,000. This sudden increase is due to the discovery of oil and gas and its intensive development in the late1960's and 1970's.

Climate

The climate of the Grande Prairie region is typical of the western Canadian Prairies, with moderate to warm summers, and cold winters. This area is noted for the relatively long frost free period of 117 days per year which allows for intensive agricultural production at these high latitudes (Twardy and Corns 1980). River valleys, due to their low altitude, are distinctly warmer and drier than the surrounding prairie. This is most marked at Dunvegan, where on the south-facing valley slopes an unusual flora (including cacti and other southern species) is found.

Soils

The favourable climate and parkland vegetation in the prairie areas has resulted in the development of Dark Grey Chernozems. Solonetzic soils are commonly found developed on lacustrine sediments. At higher altitudes, Grey Luvisols are typical of well drained sites, with organic soils found in poorly drained sites. Regosols are found on the limited flood plains of the major valleys and Brunisols are characteristic of soil development on the dune field south of Grande Prairie (Odynsky *et al.* 1956, 1961; Odynsky and Newton 1950).

Vegetation

The entire region lies within the Boreal Forest as defined by Rowe (1972). The area may be further divided into the forest and prairie regions. The prairies are now modified extensively by agriculture, but originally consisted of grassland vegetation with isolated aspen (*Populus tremuloides*) stands. The grasslands consisted of a *Agropyrum-Stipa-Carex* community, with abundant herbs and shrubs (Moss 1952; Wilkinson 1981). The origin of the Peace River grasslands is of considerable interest as they form an isolated pocket within the Boreal Forest, 400-500 km northwest of the nearest similar community. This problem is reviewed extensively by White (1983). Raup (1941) suggested that they are a remnant of more extensive grasslands developed during the

Altithermal. North (1976) thought that they developed during the Holocene as colonisers of recently drained lakes, with an unstable substrate preventing further tree growth. Ferguson (1980) believed that human influence in the form of burning maintained the grassland. Probably the best explanation is that of Moss (1952) and Wilkinson (1981) who suggested that edaphic factors, particularly solonetzic soils which form a hard clay pan, inhibit tree growth. This is supported by the pollen data of White (1983).

Forested areas are dominated by aspen poplar (*Populus tremuloides*), which is associated with white spruce (*Picea glauca*), and rarely lodgepole pine (*Pinus contorta*). Shrubs and herbs form the understory, commonly with cranberry (*Viburnum edule*), rose (*Rosa acicularis*), labrador tea (*Ledum groenlandicum*) and bearberry (*Arctostaphylos uva-ursi*). Poorly drained sites also show balsam poplar (*Populus balsamifera*), birch (*Betula papyrifera*) and black spruce (*Picea mariana*)(Twardy and Corns 1980; Odynsky and Newton 1950; Odynsky *et al.* 1956, 1961; White 1983).

Bedrock Geology

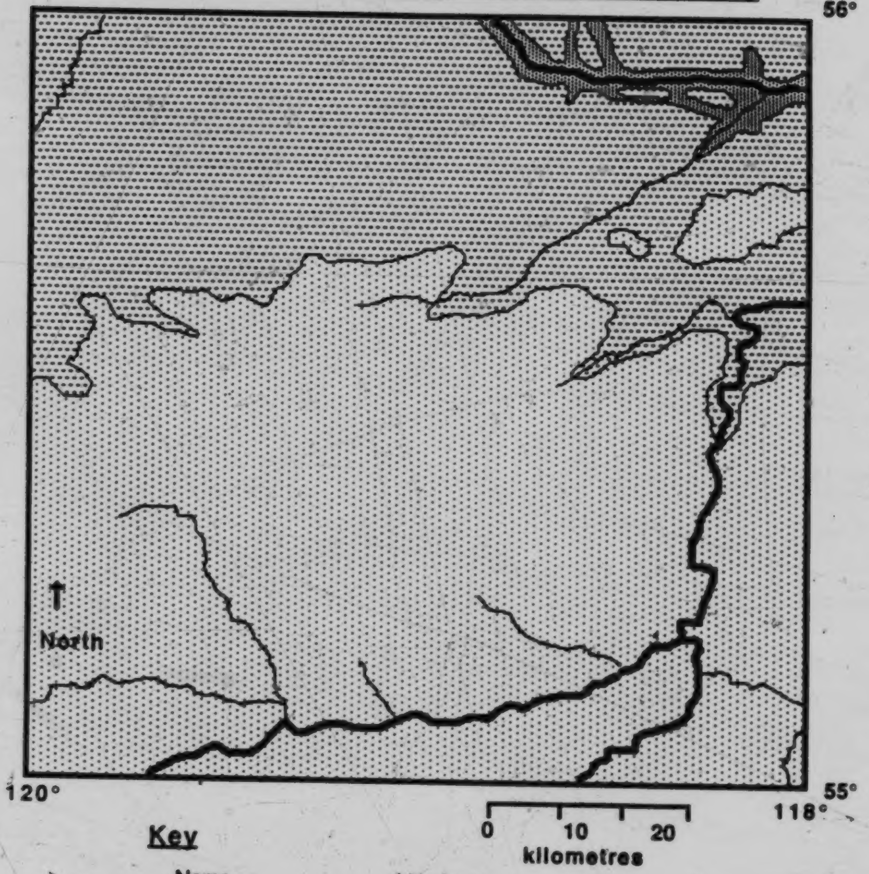
Initial studies in the area were conducted by Selwyn (1877) and Dawson (1881). McLearn (1918) delineated the major bedrock formations exposed along the Peace River and assigned them to the Upper Cretaceous. McLearn and Kindle (1950) summarised the results of many years work on Cretaceous stratigraphy throughout the foothills. Stott (1975) reviewed the Cretaceous in northeastern British Columbia and adjacent areas of Alberta and Jones (1966) discussed the bedrock geology of the Peace River region, including the Grande Prairie sheet. The Cretaceous bedrock in the Grande Prairie map sheet dips gently (2-10°) to the south, and is exposed along the major river valleys and on the tops of the Saddle Hills (Table 1, Figure 3).The oldest rocks exposed (in the

Table 1:- Bedrock Geology, Grande Prairie area (after Stott 1975)

The bedrock throughout the area is of Late Cretaceous age.

Age	Group	Formation	Member	Lithology
Campanian-Maestrichtian		Wapiti		continental sandstones, shale and coal, common iron concretions
Santonian-Campanian	Smoky	Puswaskau		marine shales
Santonian	Smoky	Bad Heart		shallow marine sandstones, shales, iron concretions
Turonian-Coniacian	Smoky	Muskiki		marine shales
Turonian	Smoky	Cardium		thin sandstones, shale, chert pebbles
Turonian	Smoky	Cardium	Bay Tree	chert pebble conglomerate and sandstones
Cenomanian-Turonian	Smoky	Kaskapau		marine shales, with shallow marine sandstone members at base
Cenomanian	Smoky	Kaskapau	Howard Ck.	shallow marine sandstone
Cenomanian	Smoky	Kaskapau	Pouce Coupe	shallow marine sandstone
Cenomanian	Smoky	Kaskapau	Doe Creek	shallow marine sandstone
Cenomanian		Dunvegan		shallow marine pro-delta sandstones and shales

Figure 3:- Bedrock Geology, after Hackbarth, 1974


56°
North
120°
55°
118°
0
10
20
kilometres

Key

	Name	Lithology
░	**Wapiti Formation**	non-marine clayey sandstone, mudstone, bentonite, coal
▒	**Smoky Group**	marine shale with concretionary iron
▓	**Dunvegan Formation**	deltaic/ marine sandstone, siltstone and shale

northern part of the map sheet) are the early Late Cretaceous carbonaceous sandstones and shales of the Dunvegan Formation. The type section for the Dunvegan Formation is on the banks of the Peace River above Dunvegan Historic Site (Dawson 1881) and it is commonly exposed elsewhere along the Peace River. It is considered to have been deposited in shallow marine conditions proximal to a major delta recognised to the northwest of the Grande Prairie area (Stott 1975). Most of the bedrock of the Grande Prairie region north of the Saddle Hills is that of the Smoky Group, composed mainly of marine shales of the Kaskapau, Muskiki and Puswaskau Formations. These are well exposed along the Smoky River. These marine intervals are separated by thin sandstones and conglomerates of the Cardium and Bad Heart Formations. Towards the base of the Kaskapau Formation in the north of the study area near-shore sandstones are found- the Howard Creek, Doe Creek, and Pouce Coupe Sandstones (Stelck and Wall 1954; Warren and Stelck 1940). The Cardium Formation is thin in the Grande Prairie area, and only outcrops along the Smoky River, where it takes the form of a chert pebble horizon lying below the Bad Heart Formation (Jones 1966). Stelck (1955) described the Baytree conglomerate, a massive black chert and quartzite conglomerate which outcrops south of Baytree in the northwest of the map area. It is poorly consolidated and has been exploited for gravel. It is considered by Stott (1975) to be a member of the Cardium Formation. The Bad Heart Formation outcrops along the Smoky River and in the Spirit River area, and consists of marine argillaceous sandstone, quartzose sandstone and ferruginous sandstone. The Bad Heart Formation was at one time considered to be a member of the Cardium Formation but Stelck (1955) showed that it is stratigraphically distinct.

The Smoky Group grades up into the Wapiti Formation, which constitutes the exposed surface bedrock in the south of the map sheet, as well as the Saddle Hills. The Wapiti Formation consists of continental sandstones, with shale and coal, and abundant iron concretions. Bentonite beds are found associated with coal, and rarely thin strata of freshwater limestone occur (Jones 1966). It is the source of dinosaur fossils, with notable localities being the summit of Kleskun Hill, and at the confluence of Pipestone Creek and the Wapiti River. Exposures are found in the Wapiti River valley, at Kleskun Hill, and are widespread in the Saddle Hills.

Rahmani and Lerbekmo (1975) discussed the provenance of Upper Cretaceous sandstones throughout Alberta, and demonstrated by the use of heavy minerals that the source of these rocks was the Omenica geanticline. Rahmani and Lerbekmo did not report samples from the Grande Prairie region, but extrapolation of their heavy mineral provinces northwards suggests that typical bedrock heavy mineral assemblages in the Grande Prairie area probably contain epidote, clinozoisite, garnet, and sphene as major components.

Rutherford (1930) thought that cross bedded sandstones and shales exposed at the crest of Saskatoon Hill might be Tertiary as they were similar in appearance to the Paskapoo Formation. Jones (1966) suggested, however, that these rocks are part of the Wapiti Formation and thus Late Cretaceous. Odynsky and Newton (1950) suggested that a gravel deposit containing predominantly quartzite pebbles and a bentonite bed, found at the crest of the Saddle Hills, was probably Tertiary.

Clast provenance is commonly used in glacial geology as a means of identifiying the origin and flow direction of the ice that deposited the glacigenic sediments. Thus it is important to have an understanding of the bedrock geology of the potential source areas of ice flowing into the Grande Prairie region. These source areas (as discussed below) are those of the Laurentide ice sheet, flowing from the Keewatin area to the northeast into the study area, and the Rocky Mountains, with ice being derived either from local mountain ice in the Front Ranges, or from the Cordilleran ice sheet, forming a major ice cap centred on the Main Ranges of the Rockies (Mathews 1980).

Throughout Alberta red or pink granites and gneisses are considered to be diagnostic of material transported from the Canadian Shield. Granitic rocks are also found in the Rockies (although not in the Front Ranges) but tend to lack the distinctive pink colour, being predominantly grey. The presence of such pink or red granite or gneiss clasts in any sediment is a sign that Laurentide glaciation has covered the area prior to or synchronous with its deposition. Drainage throughout the Quaternary has followed the pattern of modern drainage down a regional southwest to northeast slope, and thus such material must originally have been transported in a glacial system, able to flow up a regional slope, rather than in a fluvial system. Other rock types which are similarly transported include distinctive poorly cemented pink, quartz-rich sandstones of the Precambrian Athabasca Formation. These sediments outcrop at the edge of the Shield in the Lake Athabasca region. Also derived from this area are Devonian limestones, which can only be used as a definite indicator of Laurentide glacial transport if fossils are preserved.

Identifcation of Cordilleran glaciation by provenance is more difficult, as from Cretaceous time onwards most sedimentary systems active in the area carried rocks derived from the Cordillera in large quantities, particularly quartzite and chert, but also limestones and dolostones (Jones 1966, Stott 1975). Mathews (1980) suggested that Cordilleran derived material that is too fragile to survive long distance fluvial transport may be used as an indicator of Cordilleran provenance in glacigenic sediments in the Peace River area. In the Charlie Lake map area, northwest of the Grande Prairie sheet, low grade schists and slates thought to be derived from the Kaza, Ingenika and Missinchinka schists in the Rocky Mountain Trench are thus considered to be diagnostic of glacial transport from a western source (Mathews 1978).

Interpretation based on provenance studies is complicated by a number of factors. When considering clast proportions, sediment may contain large amounts of material derived from local bedrock, masking differences in erratic composition. Without detailed petrographic work it can be difficult to distinguish Athabasca sandstone from quartzites derived from the Rocky Mountains; and between limestones of eastern and western origin (Mathews 1978). A further problem is that of reworking of previously deposited glacial sediment, where ice of western origin might easily incorporate pink or red granites, or Laurentide ice could incorporate and preserve fragile clasts of western provenance.

Previous work

Both Selwyn (1877) and Dawson (1881) noted the presence of surficial deposits in the area. Dawson in particular remarked on the distribution of "brown silts" and "boulder clay", stating that the latter is confined to upland areas. He speculated that whereas the boulder clay was glacial drift, the silt had:-

> "evidently been deposited by a comparatively tranquil body of water not loaded with ice, probably toward the close of the glacial period, and has either never been laid down on the ridges and undulations....or has been

removed from them" (Dawson 1881, p 66).

Dawson also noticed the distribution of erratics, finding the western limit of Laurentide erratics close to Pouce Coupe. In following the glacial concepts of the day, Dawson believed that boulder clay was deposited in water carrying large icebergs, but explained the distribution of Laurentide and Cordilleran erratics by postulating a large body of water being supplied with ice from both the Rocky Mountains, and the Canadian Shield.

Descriptions and preliminary maps of surficial deposits of the Grande Prairie area are found in the reconnaissance work of the Alberta Soil Survey (Odynsky and Newton 1950; Odynsky *et al.* 1956, 1961). In the east part of the Grande Prairie sheet, two Laurentide tills overlain by glacio-lacustrine sediments were recognized. In the west, only one Laurentide till was described, overlain by lacustrine deposits which were thought to be overlain in turn by a thin Cordilleran till.

Henderson (1959) mapped the western half of the Winagami map sheet, to the east of the Grande Prairie sheet (Figure 4), and found four Laurentide tills. The oldest was seen at one locality only, and was called the "ancient till" by Henderson. The "lower till" was also seen rarely, and was distinguished by an abundance of clasts derived from the Canadian Shield. The "middle till" formed a continuous surface sheet over the area, contained abundant Shield clasts, and was correlated on the basis of its brown colour and typical blocky fracture. The "upper till" was distinguished by a low stone content and clay rich matrix, and was only found in topographic lows. It was suggested by Henderson to have been deposited in a re-advance during the same glaciation that deposited the "middle till". He further suggested that the clay rich nature of the till is due to advance over glaciolacustrine deposits, and that the maximum advance was

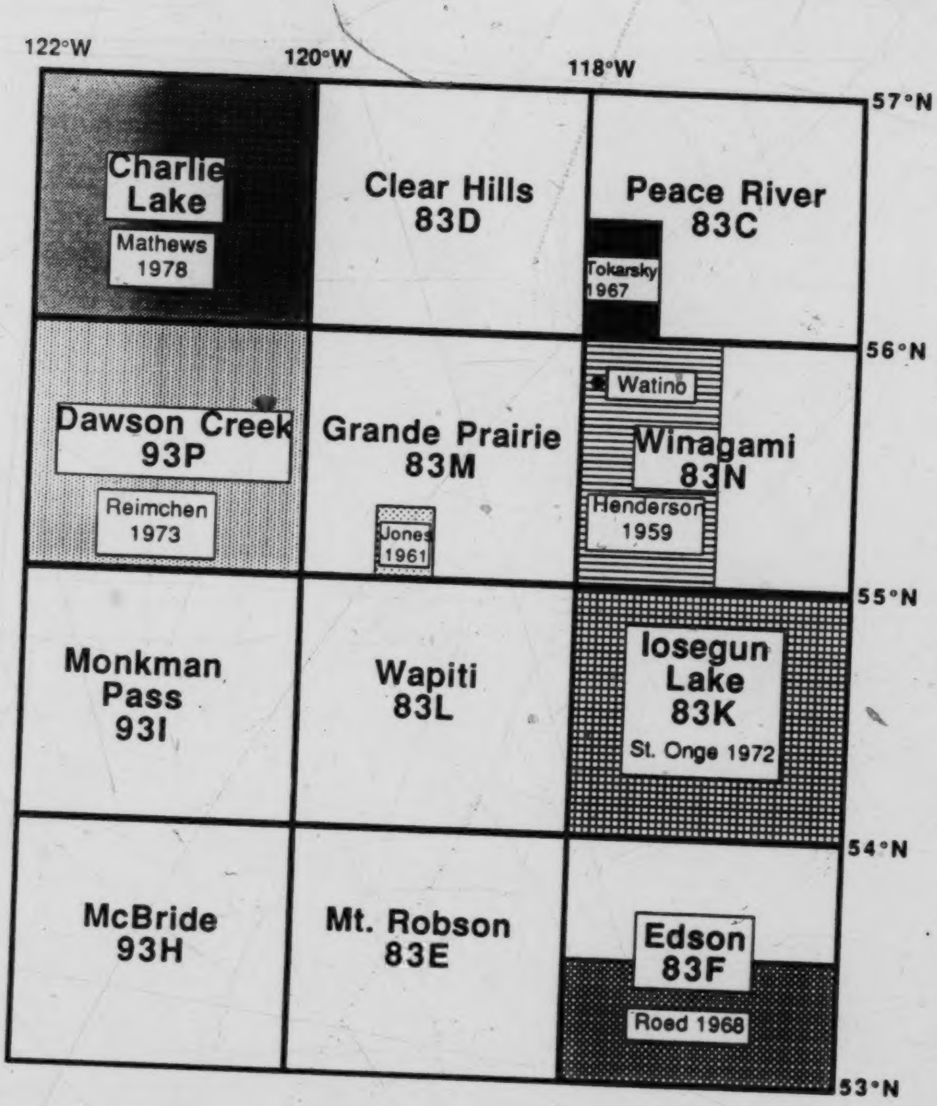

122°W
120°W
118°W
57°N
56°N
55°N
54°N
53°N
Charlie Lake
Mathews 1978
Clear Hills 83D
Peace River 83C
Tokarsky 1967
Dawson Creek 93P
Reimchen 1973
Grande Prairie 83M
Jones 1961
Watino
Winagami 83N
Henderson 1959
Monkman Pass 93I
Wapiti 83L
Iosegun Lake 83K
St. Onge 1972
McBride 93H
Mt. Robson 83E
Edson 83F
Roed 1968

Figure 4:- Previous work in west-central Alberta

Names and numbers refer to NTS map sheets marked by the Fish Creek Moraine, a poorly defined ridge interpreted to be a terminal moraine.

Tokarsky (1967) investigated the geology and groundwater resources of the Grimshaw region to the northeast of the Grande Prairie sheet (Figure 4), with particular emphasis on buried channels. He recognised two major channels lying beneath a single till sheet; the Shaftesbury channel, paralleling the modern Peace River; and the Berwyn channel, a northwesterly tributary. He also defined three levels of deposition in these systems; a high level gravel unit, the Grimshaw gravel, thought to be a high terrace of the main Shaftesbury channel; an intermediate level terrace gravel; and the main channel gravels, well exposed near the town of Peace River. The higher two levels show no evidence of material transported from the Canadian Shield, and are thus pre-glacial. The channel gravels show in one location a transition from pre-glacial to glacial gravels, but the nature of contacts between these units is not discussed.

Jones (1961, 1966) worked in the Beaverlodge area and delineated pre-glacial gravels lying in buried valleys overlain by till (showing evidence of one Laurentide advance) and lacustrine deposits. He mapped the area around Beaverlodge (Figure 4), and investigated the properties of the single till sheet, using clast lithology, and heavy mineral analyses. Jones (1966) mapped the surficial deposits between Peace River and Grande Prairie on a scale of 1:1,000,000.

Holter (1972) produced a reconnaissance study of sand and gravel resources in the Grande Prairie area, with 270 shallow drill holes, mainly in the southern half of the 83 M map area. The position of the Wembley Channel originally posulated by Jones (1961) was confirmed by this drilling, and Holter thought that he could identify terraces to these channels. He locates a kame on the flanks of Saskatoon Hill, and outwash deposits to the south of the map area. Holter concluded that alluvial terraces constitute the most useful sources of sand and gravel in the area.

Hackbarth (1974) described the hydrogeology of the map sheet, and provided a map of bedrock topography (Carlson and Hackbarth 1974). The map shows three major buried channels, the Wembley channel, identified by Jones (1966), the Shaftesbury channel (Tokarsky 1967), and the Bezanson channel (Figure 5). All channels run approximately parallel to modern rivers, the Wembley channel along the Beaverlodge, the Shaftesbury along the Peace, and the Bezanson parallel to the Smoky. These channels were mapped by correlation of seismic data and water well logs, combined with known exposures of gravels overlying bedrock. These channels also mark the location of the thickest surficial deposits, with thicknesses exceeding 120 m along the Bezanson and Shaftesbury channels (Figure 6).

May (1977) discussed sedimentology of glaciolacustrine deposits in the Edmonton and Peace River areas. He did not identify the location of his sections, but provided a sedimentation model that emphasized the presence of a transition between lodgment till and diamictons deposited in a subaquatic environment.

Reimchen and Rutter (1972) and Reimchen (1980) mapped the Dawson Creek sheet (Figure 4) and described three Cordilleran advances (tentatively assigned to Illinoisian, Early and Late Wisconsinan) and one to two Laurentide advances with fluvial and lacustrine deposits separating the last two Cordilleran advances. St. Onge (1968, 1972a) identified two Laurentide tills in the Fort

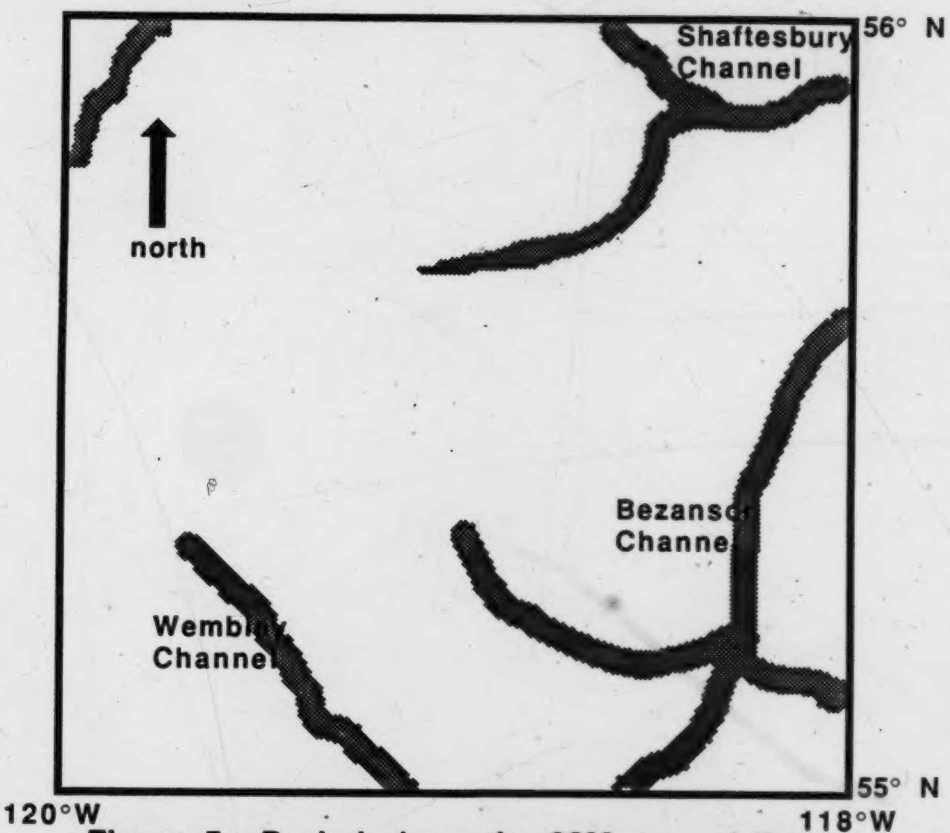

Shaftesbury
Channel
56° N
north
Bezanso
Channe
Wembl
Channe
55° N
120°W
118°W

Figure 5:- Buried channels, 83M map sheet

The map is adapted from that of Carlson and Hackbarth (1974), based on seismic shothole and water well data

Key

buried channel (pre-glacial)

modern rivers

0 kilometres 50

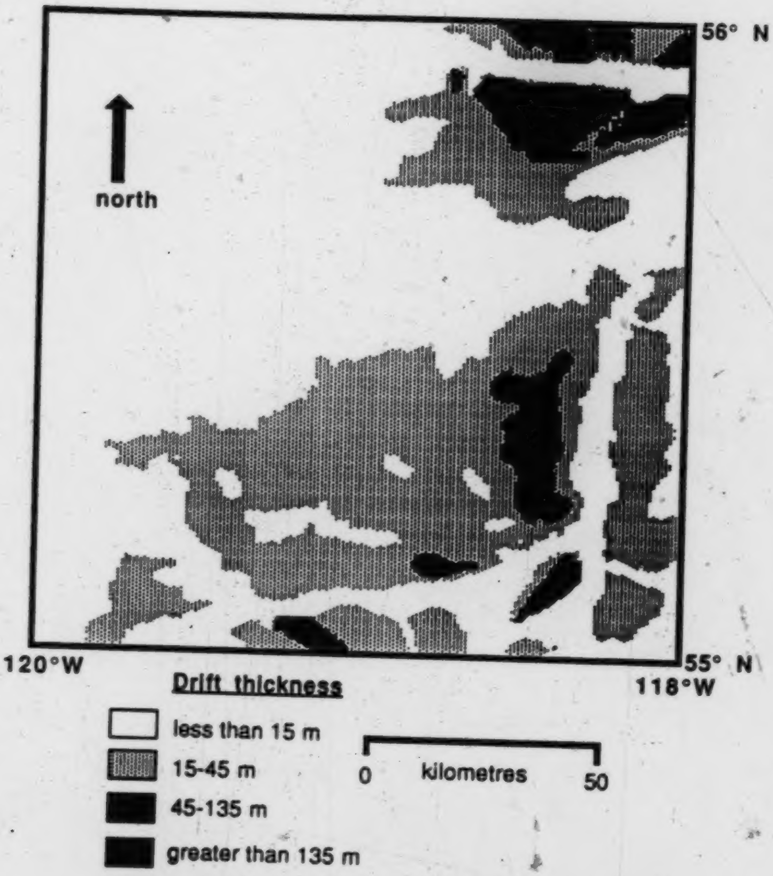

56° N
north
120°W
55° N
118°W
Drift thickness
less than 15 m
15-45 m
45-135 m
greater than 135 m
0
kilometres
50

Figure 6:- Drift thickness, 83M map sheet

Adapted from the map of Carlson and Hackbarth (1974).
Data density in northwest map corner is low to non-existent.

Assiniboine area separated by glaciofluvial sands containing a detrital wood fragment dated at 52,200 ±1760 BP (GSC-1019-2)(Table 2). The sample may have been contaminated by lignite and the date was considered infinite by St.Onge (1972a).

Mathews (1963, 1972, 1978, 1980) mapped the Charlie Lake sheet in detail (Figure 4), and extended this work on a reconnaissance basis into the Grande Prairie sheet which lies directly to the southeast. Mathews (1978) described the stratigraphy in the Charlie Lake map sheet as showing two Laurentide tills very similar in appearance and separated clearly by interglacial silts at only one locality. The upper till was identified by Mathews (1980) as Late Wisconsinan. In near-continuous exposures of this till along the Peace River a gradational change in clast lithology between typical Rocky Mountain and Laurentide types was seen. On this basis he suggested that ice from east and west coalesced in the Late Wisconsinan, and that an ice-free-corridor did not exist. The lower till was therefore thought to be pre-Late Wisconsinan. Evidence of an earlier Laurentide advance was provided by gravels underlying the lower till which showed clasts of Laurentide provenance. Only one Cordilleran advance was recognized and thought to be Late Wisconsinan. Based on shorelines of glacial Lake Peace, Mathews (1980) described a number of deglacial stages (Table 3). This related to and extended the work of St. Onge (1972b) in central Alberta.

Rutter (1976, 1977a) investigated the stratigraphy of deposits in the upper Peace River, and suggested four Cordilleran advances, three of which were thought to be Late Wisconsinan, or Early Holocene. The most extensive advance (Early Portage Mountain) is thought to have coalesced with Laurentide ice

Table 2: Radiocarbon dates in the Grande Prairie Region

This table is mainly compiled from Jackson and Pawson (1984). This reference is given if the date was originally only published in Geological Survey of Canada date lists, otherwise the first published source is referenced. Few dates are available for the 83M sheet, so information from map sheets abutting the 83M sheet is included.

Source	Lab #	Sample type	Location	Age (B.P.)
Sub-till dates				
St. Onge (1972)	GSC-501	wood from sand below till	Goose River, 83K	>42,500
Westgate *et al.* (1971, 1972)	GSC-1020	wood from massive fine grained sediments	Watino, 83 N	43,500±620
Westgate *et al.* (1971, 1972)	GX-1207	wood from massive fine grained sediments	Watino, 83 N	>38,000
Westgate *et al.* (1971, 1972)	I-2516	wood from massive fine grained sediments	Watino, 83 N	35,500+2300 -1800
Westgate *et al.* (1971, 1972)	I-2615	wood from massive fine grained sediments	Watino, 83 N	35,500+3300 -2300
Westgate *et al.* (1971, 1972)	I-2616	wood from massive fine grained sediments	Watino, 83 N	34,900+3000 -2000
Westgate *et al.* (1971, 1972)	I-4878	wood or peat from massive fine grained sediments	Watino, 83 N	27,400±850
St.Onge (1972)	GSC-1019	wood from sands between two tills	Ft. Assiniboine, 83J	52,200±1760[1]
Bobrowsky (1988)	TO-708	wood underlying mountain till	Finlay River	15,180±100
Liverman *et al.* (1989)	AECV-414C	wood from pre-glacial gravel	Watino, 83N	>40,170
Liverman *et al.* (1989)	AECV-415C	wood from pre-glacial sand	Watino, 83N	36,220±2520

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[1] considered infinite by St.Onge (1972b)

Table 2:-continued

Source	**Lab #**	**Sample type**	**Location**	**Age (B.P.)**
Liverman *et al.* (1989)	AECV-416C	wood from pre-glacial sand	Watino, 83N	31,530±1440
Liverman *et al.* (1989)	AECV-428C	wood from pre-glacial gravel	Simonette River, 83M	37,010±2690
This study	GSC-4623HP	wood from pre-glacial gravel (same site as AECV-428C)	Simonette River, 83M	>51,000
Supra-till dates				
White *et al.*(1979)	Wat-361	organic muds	Boone Lake 83M	>30,000[2]
White *et al.*(1979)	Wat-406	organic muds	Boone Lake 83M	17,570±650[2]
White *et al.*(1985)	SFU-223	wood	Boone Lake 83M	11,700±260
Mathews (1978)	GSC-2034	tooth from post-glacial gravels	Taylor, 93A	27,400±580
Mathews (1980)	I-2244A	mammoth tusk from ice contact gravels	Portage Mountain 94 B	11,600±1000
Mathews (1980)	GSC-2859	as above (redated)	as above	25,800±320
St.Onge (1972b)	GSC-508	gastropod shells	Little Smoky River 83 K	12,190±350
St.Onge (1972b)	GSC-694	gastropod shells	Little Smoky River 83 K	13,510±230
St.Onge (1972b)	GSC-698	gastropod shells	Little Smoky River 83 K	13,580±260
Jackson and Pawson (1984)	GSC-2895	bone from terrace	Watino 83N	10,200±100
Jackson and Pawson (1984)	GSC-2902	bone in terrace	Watino 83N	10,200±100
Fladmark *et al.* (1988)	SFU 454	collagen from bone	Charlie Lake Cave 94A	10,770±120
Fladmark *et al.* (1988)	SFU 300	collagen from bone	Charlie Lake Cave 94A	10,450±150
Fladmark *et al.* (1988)	SFU 378	collagen from bone	Charlie Lake Cave 94A	10,380±160
Burns (1986)	S-2614	wapiti antler from 50 m terrace	Watino, 83N	9075±305
Burns (1987)[3]	AECV272C	wapiti rib	Watino 83N	9920±220
Jackson and Pawson (1984)	GSC-2865	bone from terrace	Peace River 84C	9880±130

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[2] both considered to be contaminated by dead carbon by White *et al.* (1985)

[3] J. Burns, Provincial Museum of Alberta, personal comunication, 1987

Table 2:-continued

Source	Lab #	Sample type	Location	Age (B.P.)
Jackson and Pawson (1984)	GSC-2004	organic mud	Sulpher Lake 83D	11,000±200
Jackson and Pawson (1984)	GSC-1998	organic mud	Dollar Lake 83N	10,200±110
Blake (1986)	GSC-3520	organic mud	Lone Fox Lake 83D	10,700±140
Blake (1986)	GSC-3544	organic mud	Yesterday Lake 83D	10,000±150
Mathews (1978)	GSC-1548	gastropod shells	Dawson Creek 93P	9960±170
Mathews (1978)	GSC-1654	gastropod shells	Dawson Creek 93P	10,400±170
Bobrowsky *et al.* (1988)	AECV-583C	bulk sediment from low terrace	Peace River 84 C	7300±110
Jackson and Pawson (1984)	GSC-2802	charcoal from terrace underlying palaeosol	Grande Prairie 83M	4540±230
Halsey (1989)	AECV-627C	organic detritus from silts underlying dune sands	Grande Praire 83M	4030±180
This study	GSC-4177	charcoal from silts overlying palaeosol in dune sands	Grande Prairie 83M	2030±90

Table 3:- Glacial lake stages of Mathews (1980)

Name	strandline altitude (m.a.s.l)	spillway	spillway altitudes (m.a.s.l)	comments
phase 1	1130-900	various	-	minor high level lakes
Bessborough	830	Pass Creek	840	correlates with Iosegun I and II of St.Onge (1972b)
phase 3	800	unknown		possibly equivalent to Iosegun III of St.Onge (1972b)
Clayhurst	690-660	Fish Creek Moraine	680-650	
Indian Creek	630	Iroquois Lake spillway	590	

Further lake development (stages 6 and 7) took place to the northeast of the Grande Prairie map area, and is not relevant to the present study.

Bobrowsky (1988) provided evidence that the last Cordilleran advance in the Peace River Valley was late in the Late Wisconsinan, with ice-free conditions in the Rocky Mountain Trench until at least 15,000 B.P. (Table 2). He also suggested that this advance was restricted to the mountain front.

Timing for the last Laurentide glaciation is based on radiocarbon dates from wood in the Watino beds which indicate that they are mid-Wisconsinan (Westgate *et al.* 1971, 1972) (Table 2). Watino is located 120 km northeast of Grande Prairie on the Smoky River (Figure 4) and the sediments exposed there consisted of peaty silts and clays that contained a good pollen record, plant macrofossils, molluscs, insect remains, and ostracods. This material was interpreted as showing a climate as warm as present or slightly cooler than present (Lichti-Federovitch 1975, Westgate *et al.*1971,1972). At this locality the fossiliferous beds were not overlain by till but overlie pre-glacial gravels containing no clasts of Laurentide provenance. Fenton (1984) described the section as being "about 6 m of massive, fine grained, fossiliferous sediment which is overlain and underlain by laminated, proglacial lacustrine silts and clays" (p. 63). Reimchen (1968) collected vertebrate fossils from this locality, and the section was also discussed by Churcher and Wilson (1979). They disagreed on the age of the lowermost gravel beds, with Reimchen suggesting that they are of Mid Wisconsinan age (on the basis of the radiocarbon dates on overlying sediments), and Churcher and Wilson claiming that the fauna collected was more representative of the Sangamon, and thus the gravels were separated from the overlying organic rich sediments by an unconformity.

Liverman *et al.* (1988a; 1989) discussed the Watino section, demonstrating that the basal gravel forms a conformable sequence with the overlying silt and clay. The sediments are thought to represent a history of channel abandonment and reoccupation in a moderate energy fluvial system. Examination of the provenance of the sediments revealed that they were deposited prior to Laurentide glaciation in the area, and thus the surface till is Late Wisconsinan, and represents the only Laurentide glaciation in the region.

White *et al.*(1979) reported radiocarbon dates from a core taken from Boone Lake in the Saddle Hills (Figure 2), with the lower two dates being 17,570 ± 650 B.P. (WAT-406) and >30,000 B.P. (WAT-361) (Table 2). On this basis they suggested that the Saddle Hills were not covered by Late Wisconsinan ice. White (1983) and White *et al.*(1985, 1986) discussed these dates and concluded that the samples (of bulk organic matter) were contaminated by reworked Cretaceous coal. White *et al.*(1985) estimated the age of basal organic sediments to be c.12,000 B.P., on the basis on the amount of Cretaceous palynomorphs identified in the core. They also outlined the postglacial vegetational history from pollen data and suggested that a basal tundra type pollen record indicated that the area was covered by Late Wisconsinan Laurentide ice shortly before deposition of basal lake sediments. They further suggested that this evidence supported coalescence of Laurentide and Rocky Mountain ice in the Late Wisconsinan.

Halsey (1989) examined the geomorphology and sedimentology of sand dunes south of Grande Praire, and proposed that at least two periods of aeolian sedimentation occurred in the Holocene. The first of these episodes followed deglaciation, and the second occurred sometime after 4030±180 B.P. (AECV-627), possibly due to reactivation of dunes following fire.

Field Methods

Field investigations took place in the summers of 1985-1987, with a total of four and a half months being spent in the area. Prior to the first field season, aerial photographs at a scale of 1:60,000 covering the map sheet were examined and mapped on a reconnaissance level. This enabled location of potential exposures, critical areas of investigation, and development of a basic mapping framework. The primary objective of the first field season was to ground check the aerial photographic interpretations. To this end virtually all roads in the field area were driven and, wherever surficial sediments were exposed, they were examined to determine their properties. Over 250 sections were examined in detail. Many of these exposures were of poor quality, with less than 1 metre of sediment exposed. Such exposures provided little stratigraphic information but enabled aerial photographic interpretation to be confirmed and refined.

The second field season was largely spent in section description. Approximately fifty sections located in the first field season were selected for detailed work, on the basis of quality of exposure and stratigraphic interest. This study consisted of detailed sedimentologic description, collection of samples, photography, and clast fabric measurements. Additional field work consisted of reconnaissance to the north, east and west of the Grande Prairie sheet, in an attempt to solve particular stratigraphic problems.

Laboratory Methods

Samples collected were analysed in the laboratory using the following procedures:-

1. Grain size analysis

Analysis was by a combination of hydrometer (particle settling) and sieving, following the methods of the ASTM (1964). The results were analysed using a computer program developed by D.Wynn, Department of Geology, University of Alberta, which provides a cumulative curve. Many samples contained large amounts of clay (up to 85%), and thus Folk-Ward grain size parameters are considered inappropriate for analysis of these results in that they require data that cover up to 95% of the particle distribution (Folk and Ward 1957). With high clay contents, such values can only be obtained by drastic extrapolation resulting in spurious results. Thus grain size results are summarized by sand/ silt/ clay percentages.

2. Clast fabric analysis

Clast fabric data collected consisted of 25 measurements of clasts with a:b axis ratios of 1.5:1 or greater. This data was analysed using the ORIENT computer programme developed by H.A.K. Charlesworth and others, of the Department of Geology, University of Alberta. This programme produces rose diagrams, contoured stereographic plots, and statistical summaries. The plots were contoured using a counting circle of 4% of the diagram area. Statistics produced are estimates of the three principal orientations, and their strengths (S_1, S_2 and S3 values) (Mark 1973, 1974; Woodcock 1977).

3.Clast lithology, roundness and sphericity

During fabric analysis all clasts were collected, irrespective of axis ratios. These clasts were washed, and identified under a binocular microscope. Roundness and sphericity was visually estimated using the charts of Powers (1953). Sample size was variable but usually was in the order of 50 clasts. In areas that were thought to be critical up to 100 clasts were collected and identified. In addition field identifications were made of clasts from gravel units throughout the area.

4. Sand lithology

During grain size analysis the sand component of the sample was collected. In general the sand lithology was considered to be of limited use. For some samples, however, the sand composition is critical in interpretation, and these samples were initially examined under the binocular microscope. In a few cases this was supplemented by heavy mineral separation, using lead tetrabromide (specific gravity =2.96) .

5. Engineering properties

Samples from two well exposed thick sections (Beaverlodge I and III, see Appendix 1 for locations) were subjected to standard Atterberg limit tests to determine the liquid and plastic limits (Holtz and Kovacs 1981). These determinations are considered to be only approximations, as the precision of the balance available was close to the weight losses measured. Thus the results are only accurate to within approximately ±10%.

6. Palynology

No detailed palynological work was performed, although 16 samples were processed in order to determine if further work would be justified. The processing method is that of the Palaeoenvironmental Laboratory, Department of Anthropology, University of Alberta, modified from those of Faegri and Iversen (1975) (details are given in Catto 1986). Only a few highly degraded grains were obtained from these samples, and thus more detailed study was not pursued.

CHAPTER 2:- DESCRIPTION OF MAP UNITS

The accompanying map (Figure 7, in pocket at back) represents an interpretation of the surficial geology of the area based on aerial photograph interpretation, examination of sections and other exposures on the ground, and limited bore hole data derived from the literature. The accuracy of the map is dependent mainly on access and exposure. Thus the confidence of the interpretation is low in regions of poor access, such as the Saddle Hills; and poor exposure, such as the area around Rycroft. The detail of mapping is also less in these areas.

Map units were designated initially on the basis of aerial photograph character, with areas showing similar characteristics being grouped into one unit. The map unit designations use the system described by Rutter (1977b) (Table 4). This system has been adapted by, firstly, the additional of the textural modifier f (fines), which is used for undifferentiated silt and clay. Secondly, the non-genetic term diamicton (d) is used as a replacement for till (t) which has genetic implications and is inappropriate as a textural modifier. Thirdly, the genetic origin symbol for aeolian has been changed from E to A in order to conform with English/ Canadian usage, and thus the symbol for alluvium or fluvial must be changed to F. Interpretation was refined after ground checking, when the nature of the materials composing each unit was studied. Lastly, after interpretations of environments of deposition were made for the materials investigated, a further division of map units was possible. Twenty major units were identified in the map area, and their characteristics are summarised in Table 5.

Table 4:- Map Unit designations (after Rutter 1977b)

Textural modifier	Genetic origin	Morphological modifier
g- gravel	M- morainal	b- beach
s- sand	G- glaciofluvial	c- channelled
si- silt	L- lacustrine	d- drumlinoid
c- clay	F- alluvium, fluvial	h- hummocky
f- fines (silt and clay)	C- colluvium	k- pitted
d- diamicton	A- aeolian	l-lineated (fluted)
r- bedrock	O- organic	m- rolling
p- peat (bog)	S- slump	p- plain
	R- bedrock	r- ridged
		t- terraced
		v- veneer (<1.5 m thick)
		x- complexed

Superscripts:-

A dash (-) separating two units indicates with 16-49% of the second unit

A slash (/) separating two units indicates with 5-15% of the second unit

A plus (+) separating two units indicates an unknown combination of the first and second units

A fractionated symbol (__) indicates a veneer of one unit over a thicker second unit

Table 5:- Map units

Unit #	Map symbol	Description	% map area	Air photo pattern	Topography	Slope angles	Material properties	Material origin
1	rRm+rRr	bedrock	<1	light, variable tones	varied, scarp and dip pattern, up to 100m relief	gentle-steep	mainly sandstone + shale, coal	bedrock
2	dMv rRm+rRr	diamicton veneer over bedrock	15%	light to dark variable tones	as above	gentle-moderate	sandy diamicton over bedrock	till
3	dMh	hummocky diamicton	2%	dark mottled tones	irregular hummocks up to 5m high	moderate	diamicton	till
4	dMr/dMd	ridged diamicton	10%	parallel lineations, dark-light tones	elongate ridges, 5-30 m relief	gentle	diamicton	basal till
5.	fLp	silt and clay plain	20%	dark even tones	little relief	flat	silt and clay, few coarse clasts	glaciolacustrine
6.	fLl+fLv dMr+dMp	lineated silt and clay veneer of silt over ridged diamicton	5%	parallel lineations, darkeven tones	rolling to flat	gentle	silt and clay, some coarse clasts	glaciolacustrine drape over diamict, bedrock lineation
7.	Lm dMm+rRm	veneer of clay & silt over diamicton/ bedrock	5%	mottled dark to light tones	rolling	moderate-steep	silt and clay/ diamicton and bedrock	glaciolacustrine drape over thin till and bedrock
8.	fLh	hummocky silt and clay	5%	regular mottles, light and dark tones	hummocks, 2-8m relief	gentle-moderate	silt & clay	deformed glaciolacustrine
9.	fLm	rolling silt and clay	5%	as above	low hummocks, 0-2 m relief	gentle-flat	silt and clay	as above
10.	fLp rRr	concentric lineated silt and clay	<1	even tones, concentric lineation	low	gentle	silt and clay over bedrock	glaciolacustrine silt over ice thrust bedrock
11.	fLk	pitted silt and clay	5%	even tones with irregular pits	low relief	flat - gentle	silt and clay with minor organics	glaciolacustrine silt pitted by wind

Table 5:- Map units (continued)

Unit #	Map symbol	Description	% map area	Air photo pattern	topography	slope angles	material properties	material origin
12.	fLv various	silt and clay veneer	2%	dark mottled tones	varied, conforms to that of underlying material	varied, mainly gentle	silt/ clay with many stones	ice proximal glaciolacustrine and shorelines
13.	fLv gGr	ridged sand & gravel	<1%	light tones	low ridge, 2-5 m high	gentle	poorly sorted sand & gravel	esker or kame
14.	gGm + gGc dMr	complex sand and gravel	2%	light tone, complex lineation pattern	rolling, channeled, low relief	gentle	poorly sorted sand &gravel	glaciofluvial outwash
15.	gFt+sFt	terraced sand and gravel	1%	light tones, adjacent to modern rivers	flat, channeled	flat	gravel and sand	post-glacial terraces
16.	sAh+sAv fLp	hummocks and veneer of sand	4%	light mottled tones	low hummocks	gentle	fine sand and silt over silt and clay	aeolian dome dunes and sand sheet
17.	sAr fLp+gFt	ridged sand over silt and gravels	7%	light toned U shaped lineation	sharp crested elongate ridges	moderate -steep	medium sand over gravel, silt and clay	parabolic dunes
18.	dCx+rCx	colluvium	<1%	semi-circular lineation	steep irregular slopes	steep	bedrock & diamicton	bedrock, till & glacial lake clay -re sedimented by rotational slump & debris flow
19.	gFc+sFp	modern alluvium	1%	light tones at base of river valleys	flat to terraced	gentle-flat	gravel, sand and minor silt	modern alluvium
20.	pOp+cLp	organic deposits	1%	dark tones	gentle depressions	flat	peat and clay	modern lacustrine & swamp deposits

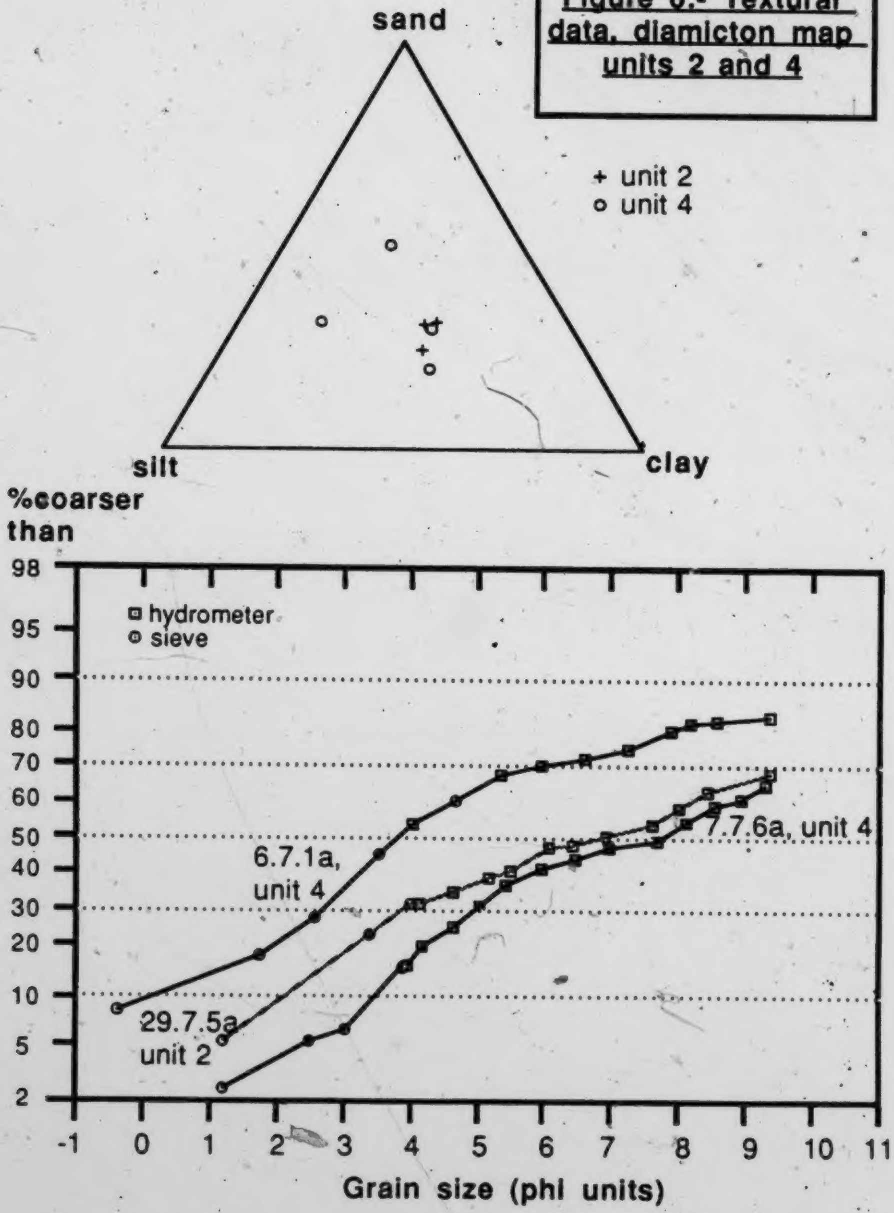
1. Bedrock (rRm+rRr)

This unit is composed of exposed bedrock, and is recognised on aerial photographs by light tone, distinctive gullying patterns, a NW-SE and NE-SW bedding/jointing pattern, and topographic position. On the ground bedrock is clearly recognised in good exposures but in poor exposures, the poorly consolidated nature of the bedrock can cause confusion with Quaternary sediments. Most of the bedrock exposed at the surface consists of sandstones with minor shales and coal. Iron concretions are common. This unit is not widespread (<1% of the map area), with major exposures only at Kleskun Hill, east of Grande Prairie. In the Saddle Hills differentiation between this and map unit 2 (see below) is not made, as the lack of access, combined with a thick tree cover makes identification uncertain. It is likely to be present on steep slopes and on topographic highs, where erosion has removed a thin diamicton cover. Bedrock is also exposed in the major river valleys, but the area exposed is too small to be mapped at the detail required, and is incorporated with map unit 18.

2. Veneer of diamicton over bedrock (dMv/rRm+rRr)

Map unit 2 is widespread in the Saddle Hills, and constitutes 15% of the map area (Table 5). On aerial photographs it appears very similar to unit 1 with light tones and prominent bedding/jointing patterns. Topographically it is varied, with prominent ridges, scarps and plateau areas. Slopes are moderate to steep. The diamicton veneer varies from less than a metre to 2-3 m. Only a few samples were taken from this unit, and show the diamicton to be of Laurentide provenance, and poorly sorted (Figure 8). The proportion of clasts is higher than diamicton seen in section elsewhere in the area

Figure 8:- Textural data, diamicton map units 2 and 4



Geomorphology and genesis

In the Saddle Hills a number of east-west trending scarps are seen, with the scarp slope to the north. Arenaceous strata within the Wapiti Formation are more resistant to erosion than argillaceous horizons, and this, combined with the southward dip, results in scarp formation. This also exercises a control on drainage with a poorly developed trellis pattern over most of the Saddle Hills.

Exposure of diamicton in the Saddle Hills is poor, and does not allow examination of sedimentary structures. The diamicton is thought to be largely basal melt-out till with some supraglacially deposited diamicton as:-

1. The topographic position of the unit, above any known glacial lake, suggests that the diamicton could not have been waterlain.

2. The unit is associated with map unit 3, hummocky diamicton, possibly deposited in an ice stagnation environment through ablation and remobilisation of supraglacial melt out till.

It is likely that the sediments were post-depositionally remobilised on any steep slopes. However, these interpretations are speculative in the absence of sedimentologic evidence.

3. Hummocky diamicton(dMh)

Map unit 3 is found on the northern and southern margins of the Saddle Hills, and constitutes 2% of the map area. It is characterised by hummocky topography, with a relief estimated at 3-8 m, dark mottled tones on aerial photographs, and a heavy vegetation cover. It was not observed in section on the ground. It is likely that it is composed of diamicton of a similar texture to that observed elsewhere in the area of the Saddle Hills (Figure 8).

Geomorphology and genesis

This unit was not observed in section. The scale and type of topography is similar to map unit 8 (hummocky silts and clays) and there is some potential for confusion. However, map unit 3 is identified in areas above the interpreted glacial lake shoreline (see below), and is thus probably composed of diamicton of glacial origin. The genesis of hummocky topography in glacial deposits is discussed by Gravenor and Kupsch (1959) and Parisek (1969), and is considered to be characteristic of deposition during stagnation of an ice sheet margin. Sedimentation takes place by sub-aerial debris flow of previously deposited sediment followed by relief inversion. Kulig (1985) indicated that geomorphically similar landforms can be generated by glaciotectonism, and by melt-out of buried ice in lacustrine sediments. Thus, without examination of good exposures through the unit, it is not possible to make an unequivocal interpretation of their origin.

4. Ridged diamicton (dMr, dMd)

Map unit 4 is found in the southwest of the map area, and over the Saddle Hills. It constitutes 10% of the map area. It is recognised on aerial photographs by a distinctive parallel lineation, accentuated by drainage. Photographic tones are dark and uneven, with the highs of the ridges lighter than the lows. On the ground the unit consists of a series of elongate ridges and grooves oriented SW-NE in the southwest of the map area, and N-S over the Saddle Hills. Individual ridges can be traced at least 10 kilometres laterally. In the southwest of the map area the spacing between ridge crests varies from 100-700 metres, and the relief between crest and valley ranges from 5-30 metres, the greater relief occurring where streams and rivers have occupied the valley bottom. On aerial photographs, the ridges can be seen to taper to a point to the northeast, whereas the southwestern termini are blunt. To the east the unit grades into unit 6 (lineated silt and clay). Over the Saddle Hills map unit 4 takes the form of parallel grooves with little relief (Plate 1). Spacing between these lineations is variable, but can be up to 2 kilometres.

Good stratigraphic sections were not found in map unit 4, exposures being limited to poor road cuts in the southwest of the map area, with only basic sedimentologic characteristics visible. The unit is composed of diamicton, with a relatively high estimated clast component. Clast lithology is varied, and shows a mixture of Cordilleran and Laurentide provenance. Three samples show varied textures (Figure 8).

Geomorphology and genesis

The absence of good sections in this unit prevents a sedimentologic interpretation of environment of deposition. Such large scale fluted terrain is commonly considered to be typical of deposition under active ice with the flutes paralleling ice flow direction (Sugden and John 1976). The less well defined parallel grooves in the Saddle Hills are interpreted as resulting from glacial erosion at the base of active ice.

The pattern of fluting in the southwest of the map area, a fan spreading from a focus in the foothills, suggests formation by ice emerging from confined flow to unconfined flow, and able to spread out to form a piedmont lobe (Figure 7). This lobe consisted of montane ice originating from the Redwillow Valley and flowing generally to the northeast. Fluting patterns in the Athabasca Valley, west of Edmonton, appear to be deflected to the south after emergence from the

Plate 1:- Aerial photograph Alberta Government AS 2315-6, 8 of lineations in the Saddle Hills. Area shown is largely map unit 4. Scale bar represents 2 km.

mountain front. Roed *et al.* (1967) and Roed (1975) suggested that this indicates coalescence with the Laurentide ice sheet at the time of formation of these landforms, with montane and Cordilleran ice being deflected south as eastern flow was obstructed by Laurentide ice. This relationship is not seen in the Grande Prairie region indicating that montane ice flow was constrained solely by topography and the gradient of the ice mass, and that coalescence with Laurentide ice did not occur at the time of formation of the flutings. The topographic control on these flutings is demonstrated by their distribution, with their greatest eastern extent being in the lowest parts of the region, and the northern limit at the foot of the Saddle Hills.

Over the Saddle Hills north-south oriented lineations are visible on aerial photographs. These are not well defined landforms and it is not certain that they are glacial in origin. They may mark bedrock structure, but Mathews (1980) suggested that they are ice flow direction indicators and that they mark the flow direction of Laurentide ice south over the area. South of the Saddle Hills these lineations exhibit a poorly defined cross cutting relationship with the flutes originating from the west. It is a questionable relationship in that both montane flutes and Laurentide lineations are poorly developed, and they are oriented at almost 180° to each other in this area. This makes identification of a cross cutting relationship very much an interpretation.

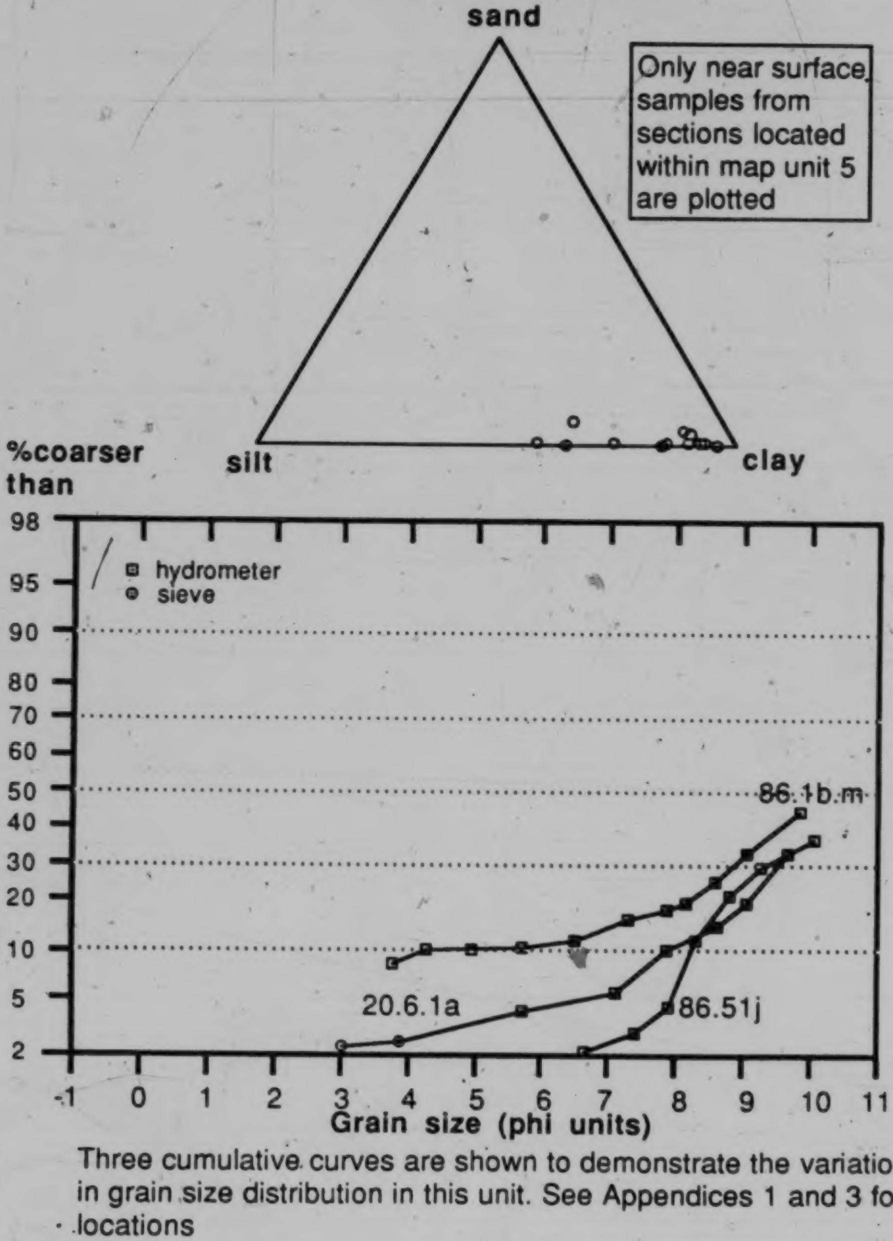
5. Silt/ clay plain (fLp)

Map unit 5 is widespread in the map area, constituting 25% of it. On aerial photographs it shows dark, even, photographic tones, and tends to be intensely farmed. On the ground, it is characterised by low relief, and is found generally in topographic lows. In numerous sections throughout the map area, it was found to consist mainly of thick sequences of laminated silt and clay, with a variable proportion of coarser clasts. Rare interbeds of diamicton were also observed. The texture of this unit is silt to clay, with little sand (Figure 9). Atterberg limit analyses performed on two sections in the southwest of the map area (Beaverlodge I and III) show that sediments of this unit plot on the standard Casagrande graph in the area of inorganic clays of moderate to high plasticity (Figure 10). The scatter of points between the U and A line suggests that both montmorillonites and illites compose the clay in the sediment (Holtz and Kovacs 1981). This is confirmed by the XRD results of Jones (1961), who reported montmorillonite, illite, chlorite and calcite as the major constituents of these sediments.

Geomorphology and genesis

The detailed sedimentology of map unit 5 will be discussed below (Chapter 6), but the dominance of graded beds of silt and clay, combined with the fine grain size and common coarse clasts which deform underlying lamination and are draped by overlying sediments, suggest that this unit was deposited in a glacial lake. The map unit is found in topographic lows, and in these areas the lakes (dammed by ice retreating to the northeast) would persist for longer than over relative highs. As the lake retreated, distance to the active ice front increased, and thus the nature of glaciolacustrine sedimentation changed. In ice-proximal settings, the proportion of ice rafted clasts is high, and rhythmites deposited by turbidity flow are interstratified with diamictons deposited by sub-aquatic debris flows (Evenson *et al.* 1977, , Eyles and Miall 1984, Ashley *et al.* 1985). In ice distal settings, the coarse clast component is minor, and

Figure 9:- Grain size distribution, unit 5, silt /clay plain



Three cumulative curves are shown to demonstrate the variation in grain size distribution in this unit. See Appendices 1 and 3 for locations

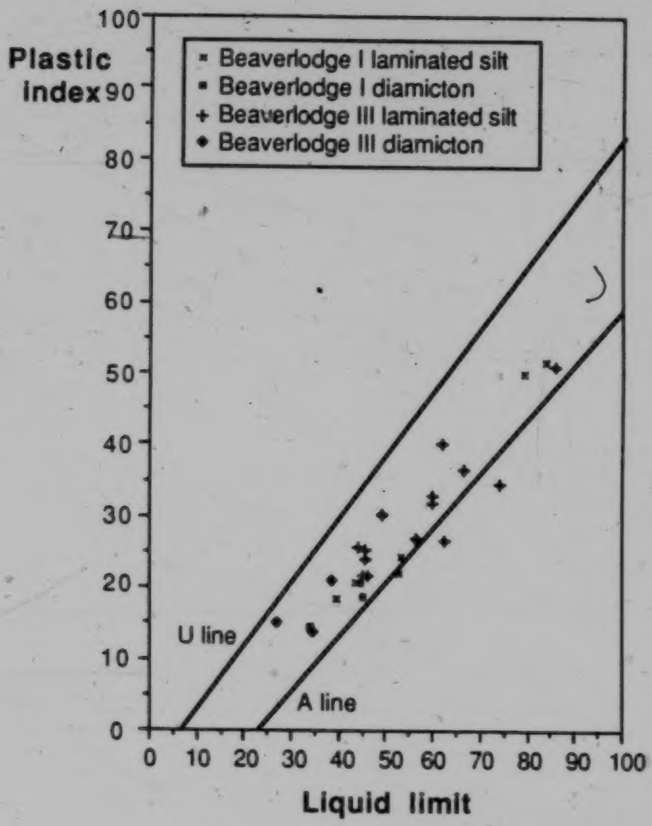


Figure 10:- Atterberg limit determinations, Beaverlodge I and III sections

Both sections lie within map unit 5 and the laminated silt data may be considered typical of the engineering properties of sediments of this unit in the southeastern part of the map area diamictons are rare or absent, with sedimentation being dominated by suspension settling, and distal turbidity currents (Ashley 1975, Eyles and Miall, 1984, Ashley *et al.* 1985).

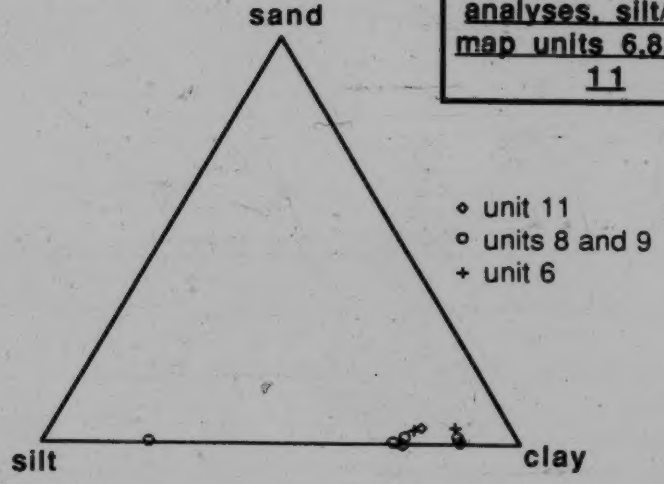
6. Lineated silt and clay (fLl)

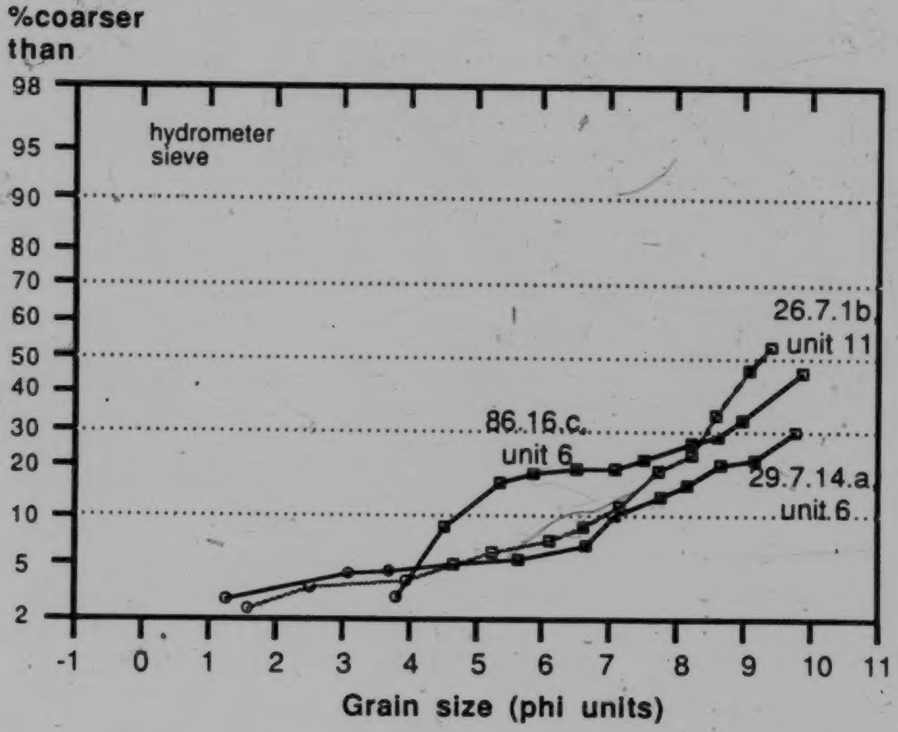
Map unit 6 composes approximately 5% of the map area, and is found associated with map unit 4 mainly in the southwest of the area, although isolated occurrences are found in the east and northeast of the map area. On aerial photographs the unit is characterised by dark, even tones, combined with a pronounced parallel lineation, with individual lineations traceable over 5-10 km, and 0.2-1 km between lineations. On the ground, relief and slopes are low, with the lineations indiscernable unless accentuated by drainage. In section the unit is composed of a blanket (1.5-5 m thick) of laminated silt and clay with some coarse clasts, overlying diamicton. The texture of the surface sediment is variable (Figure 11).

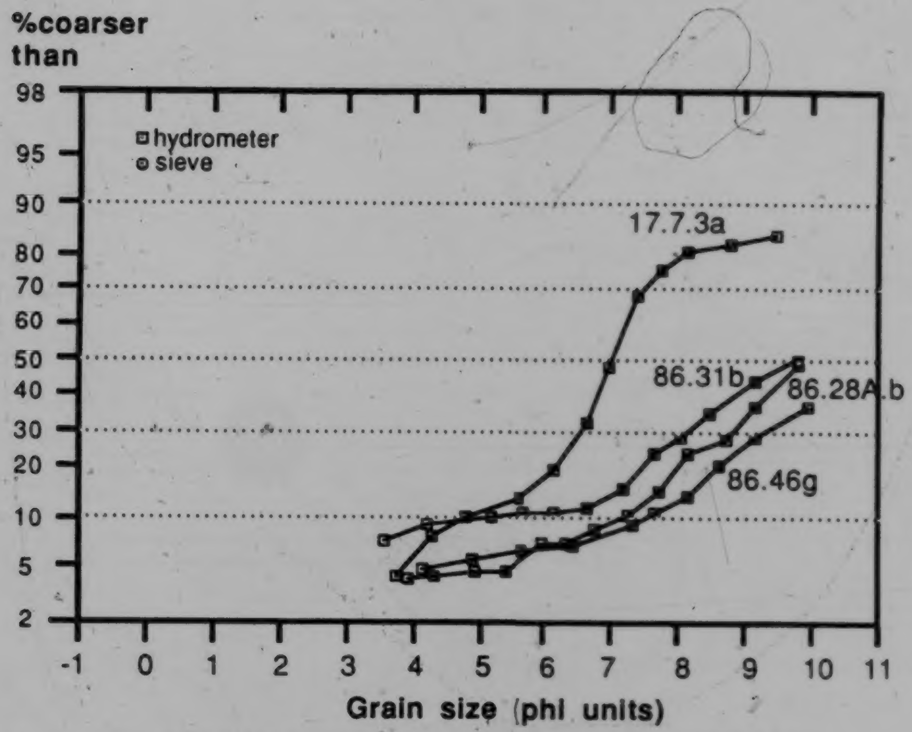
Geomorphology and genesis

In the west of the map area, map unit 6 originated by deposition of diamicton by the action of montane ice, followed by draping of the surface by glacial lake sediment. Towards the margin of such lakes on relative topographic highs, the period of existence of the lakes would be brief, and only a thin veneer of sediment would be deposited. In topographic lows the lake sediment cover was greater, with remobilisation of sediment filling irregularities in the surface. This masks the fluted topography completely on the ground, but leaves a lineated pattern visible from the air. It is likely that the silt/ clay cover is composed mainly of ice proximal glaciolacustrine sediments. Thicker sequences of lake

Figure 11:- Textural analyses, silt/ clay map units 6,8,9,and 11







Sample cumulative curves of near surface samples from sections located within map units 8 and 9

Figure11 (continued):-
Textural data, units 6,8,9 and 11

sediments show a vertical transition from proximal to distal environments.

In the east and north east of the map area, a NNE-SSW lineation is visible on aerial photographs in an area where the surface sediment consists of a blanket of lacustrine silts and clays (Plate 2). The lineation may be interpreted as glacial fluting, caused by Laurentide ice but drainage patterns indicate that bedrock jointing, parallel to the lineation, is present in the area. It is therefore possible that the lineation here is due to bedrock control, although this may have been accentuated by glacial erosion.

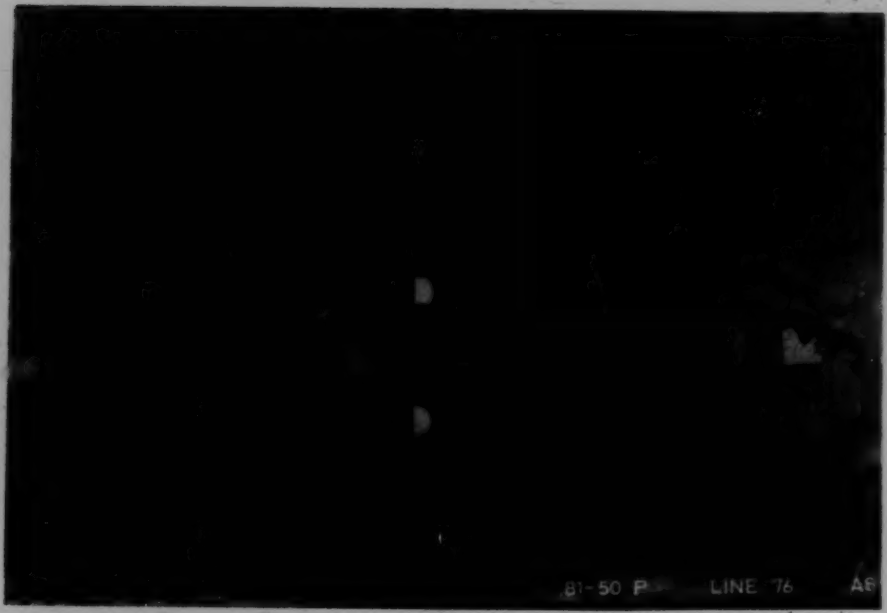
7. Veneer of clay and silt over diamicton and bedrock (fLm/dMm+rRm)

On aerial photographs map unit 7 shows uneven mottled dark to light tones. On the ground, it is characterised by rolling topography, and is restricted to topographic highs, and moderate to steep slopes. It forms 5% of the map area. It is usually associated with map unit 5 (silt/ clay plain). In section, a veneer of laminated silt and clay overlies a thin diamicton, which itself overlies bedrock. The silt and clay are rhythmically bedded, and contain coarse clasts, and diamicton interbeds. The diamicton is generally structureless. Grain size results from two samples show a variable texture (Figure 12).

Geomorphology and genesis

The variable mottled tones are due to a thin surficial cover consisting of glaciolacustrine silt and clay, overlying diamicton of undetermined origin. Well exposed sections were not located in this unit, but the glaciolacustrine sediments observed in poor exposures were mostly thin. These sediments were deposited close to glacial ice, as shown by numerous dropstones, and rare

Plate 2:-Aerial photograph Alberta Government AS 2315-138,140 of map unit 7, bedrock controlled lineations, Bad Heart River. Scale bar represents 2 km.



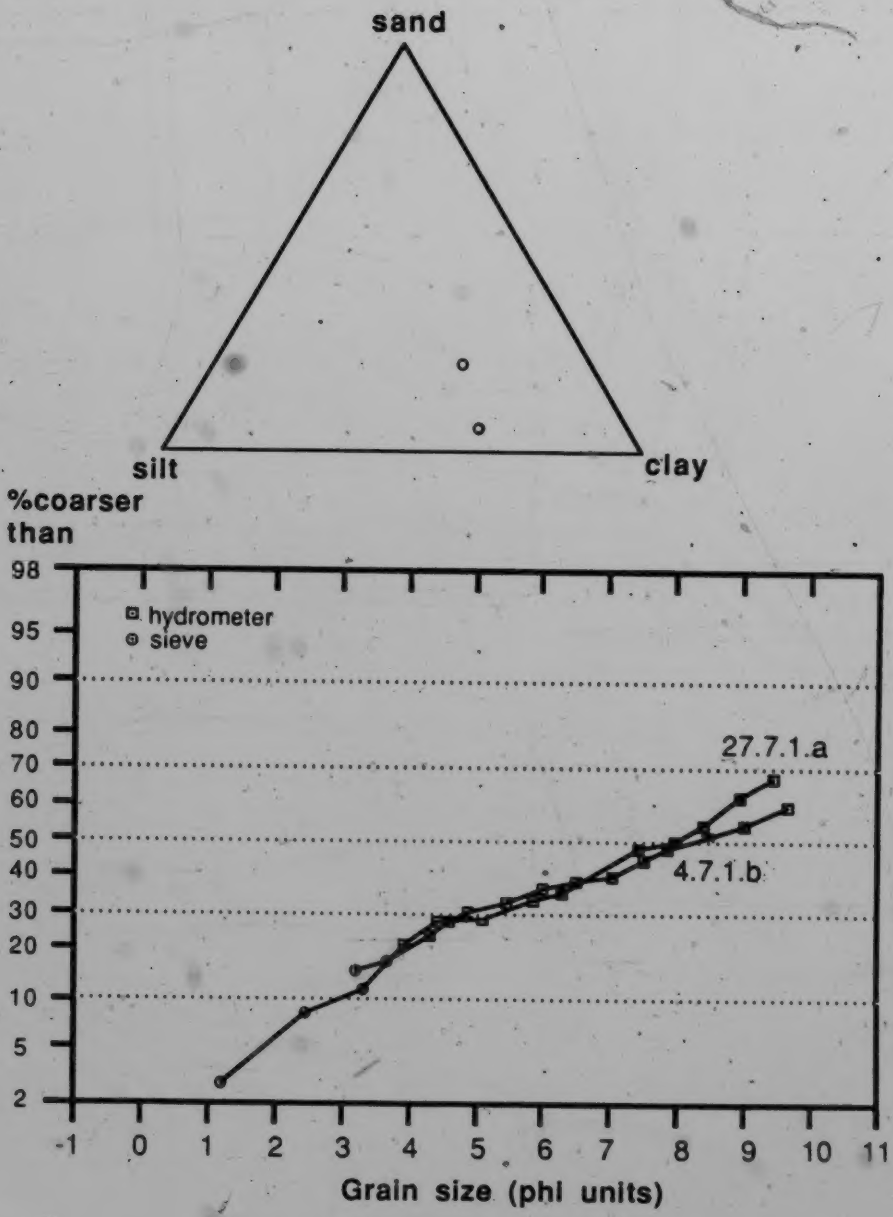


Figure 12:- Textural data, map unit 7

diamicton interbeds. The lack of cover on these topographic highs and moderate slopes is probably due to:-

i. Remobilisation of deposited sediment; either synchronous with deposition, or post-depositional.

ii. Lack of deposition; topographic highs in a lake basin would receive little sediment, as the dominant depositional mechanism would be sediment gravity flow. These flow down-slope, away from topographic highs. Much of the diamicton in the area is also waterlain, deposited by debris flow and resedimentation of till, and thus the till cover of such highs would also be thin.

Lack of well exposed sections prevents definition of the relative importance of these processes but the paucity of deformation structures in the lake sediments suggests that lack of deposition is the dominant cause of the thin lacustrine cover.

8. Hummocky silt and clay (fLh)

Map unit 8 is seen on aerial photographs as distinctive regular mottled dark to medium tones (Plate 3). It occupies 5% of the map area, adjacent to the Peace and Smoky Rivers (Figure 7). On the ground it appears as semi-regularly spaced hummocks from 2 to 8 metres high, 10 to 30 m in diameter, with 10 to 20 metres between crests. Hummock slopes are gentle to moderate. The relief of the hummocks increases towards the river valleys. The unit is closely associated with map unit 9 (see below), which borders map unit 8 away from the river valleys as relief decreases. The genesis and geomorphology of this unit will be discussed along with that of map unit 9 below. Only poor sections exist , but show the sediments composing the hummocks to be mainly silt and

Plate 3:- Aerial photograph Alberta Government AS 2316-132, 134 of map units 8 and 9, adjacent to Saddle River, south of the Peace River. Scale bar represents 2 km.

clay (Figure 11), with some cross laminated and parallel laminated fine sand. Coarse clasts are rare to absent.

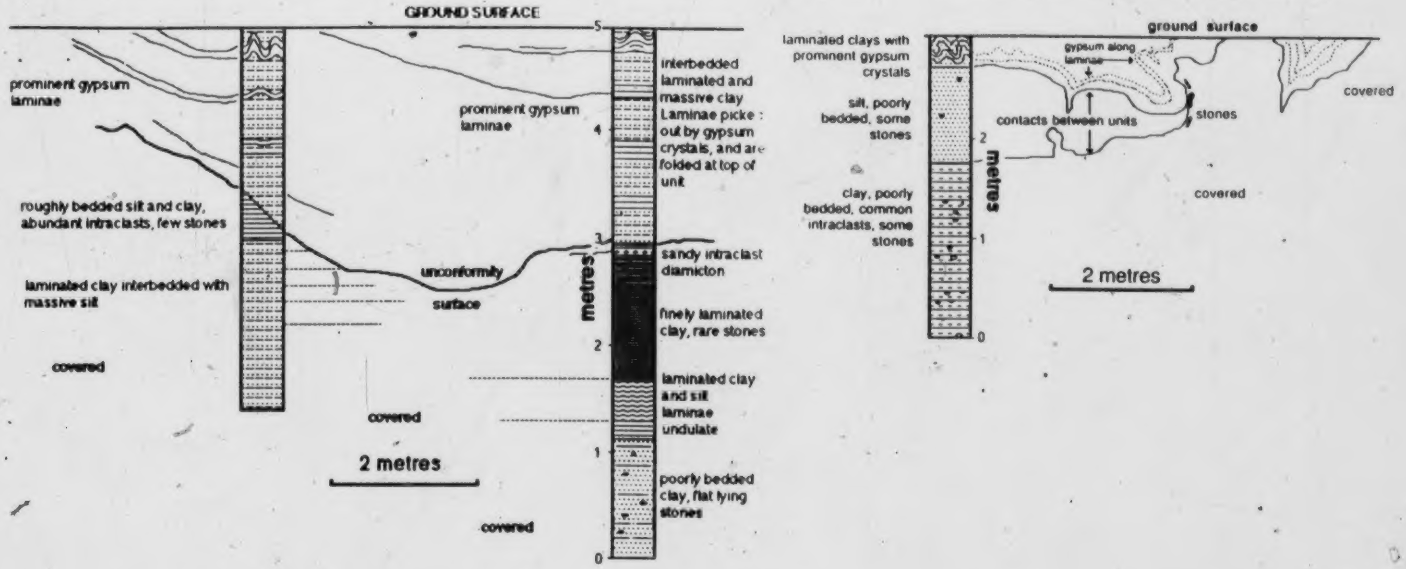
9. Rolling silt and clay (fLm)

Map unit 9 is found associated with unit 8 in the north and east of the map area, forming 5% of it. On aerial photographs it has a similar character to unit 8, only with less tonal variation (Plate 3). On the ground, low hummocks form gentle rolling topography, with a relief of 0 to 2 metres, diameters of 10 to 20 metres, and a spacing of 10 to 20 metres. Two well exposed sections (Hines Creek and Peace River) show complex deformed clay, silt and fine sand, and other poorly exposed sections expose similar sediments. With only poor exposures this map unit might be confused with map units 3 (hummocky diamicton) or 16 (hummocks of sand).

The Hines Creek section is located west of Hines Creek, north of the Peace River. The section has been exposed by a rotational slump, resulting in 75 m lateral and 15 m vertical exposure. This cuts through a low mound with a relief of 1-2 m. This topography, characteristic of map unit 9, grades into higher relief mounds of map unit 8, 100 m west.

The section exposed is complex and deformed, with the most intense deformation found at the centre of the section, which is also the highest part of the mound. Three vertical transects were described in detail, two at the north end of the exposure, the other in the centre (Figure 13). The sediments consist of mainly clay with some silt beds, laminated and bedded, with common intraclasts and few stones. Towards the top of the section clay laminae are emphasized by crystals of gypsum. On the north end of the section, this

Figure 13:-Sketch of Hines Creek section


GROUND SURFACE
prominent gypsum laminae
prominent gypsum laminae
roughly bedded silt and clay, abundant intraclasts, few stones
laminated clay interbedded with massive silt
unconformity
surface
covered
covered
covered
2 metres
metres
5
4
3
2
1
0
interbedded laminated and massive clay Laminae picke : out by gypsum crystals, and are folded at top of unit
sandy intraclast diamicton
finely laminated clay, rare stones
laminated clay and silt laminae undulate
poorly bedded clay, flat lying stones
ground surface
laminated clays with prominent gypsum crystals
silt, poorly bedded, some stones
clay, poorly bedded, common intraclasts, some stones
gypsum along laminae
contacts between units
stones
covered
covered
metres
2
1
0
2 metres

laminated clay unit is up to 2 m thick, but pinches out completely towards the centre of the section. The basal contact of this unit truncates underlying flat lying beds, forming an undulating unconformable surface that generally dips north. These laminae have been tightly folded in the centre of the section, in places forming recumbent folds (Plate 4). On the margins, deformation takes the form of gentle undulating folds. The laminae are truncated at the ground surface on either side of a central "plug" of clay. The laminae dip away from this plug, which appears to have intruded the overlying sediment as a diapir. The sediment composing the plug is clay, which is not exposed away from the zone of intense deformation. The contacts with other units are sharp, irregular and convoluted, and are nearly vertical in places. A few pebbles and cobbles are aligned along the southern contact, dipping at steep angles. The sediments show little variation in grain size distribution, being composed of between 75% and 85% clay with less than 3% sand (Figure 11).

The Peace River section is located north of the Peace River, and east of Dunvegan, in a temporary exposure caused by excavation for construction. The section cuts through a low relief hummock, 1-2 m high, and consists of a 1-2 m vertical exposure over 25 m laterally. The sediments exposed consists largely of silt and clay, and are faulted and folded. In the northeast corner of the exposure, overlying laminated clay at the base, four couplets 8-10 cm thick are exposed. The base of each couplet is composed of horizontally laminated silt, grading up into laminated clay. The beds are gently folded, with an amplitude of 4-5 cm and a wavelength of 10-20 cm. The couplets are overlain by a sequence of faulted and gently folded laminated silt and clay, with strata dipping gently to

Plate 4:-Folding of silt and clay, Hines Creek section. "Diapir" is to right of picture.30 cm of shovel handle is within frame.

the south. The top of the section shows dominantly fine sand, with silt and clay intraclasts. At the south end of the section is a similar sequence of clay at the base coarsening up to silt and clay. The sediments show abundant evidence of normal faulting, with displacements up to 40 cm, and down-throws to the south (Plate 5, Plate 6). Faults are steeply dipping, near vertical on the north side of fault blocks, but dip at lesser angles to the north on the south side. The owner of the property found clays down to 15 m during drilling a test hole for a water well.

Geomorphology and genesis

Similar landforms (known informally as "humpies") have been described by Odynsky and Newton (1950), Henderson (1959), Mathews (1978) and Mollard (1983). Henderson (1959) examined sections directly east of the 83M sheet, and found that the hummocks consisted of folded and faulted clay and silt, of lacustrine origin. He suggested that they were formed by lateral pressures caused by growth of ice wedges in the areas between the mounds.

Mathews (1978) recognised very similar mounds to those found in the Grande Prairie sheet in the Charlie Lake sheet. He noted the mounds only occurred at elevations below 645 metres, adjacent to the Peace River valley. Sections reveal an internal composition of clay rich lake sediments, with rare occurrences of sand, usually folded and faulted. The style of deformation indicated both compressional (tight folds) and extensional (normal faults) forces. The top of these mounds frequently had a depression in which fossiliferous calcareous silt had been deposited. Mathews (1978) noted that the spacing between mounds can be great compared to modern ice wedge systems, and there was no evidence of fossil ice wedge casts in the inter

Plate 5:-Peace River section. Faulted laminated and cross laminated sand overlying laminated silt and clay. Coin for scale.

Plate 6 Peace River section. Overview showing faulting of sand. Shovel is 1 m long

-mound areas. Mathews suggested that the process of formation might be analogous to that which forms pingos (Mackay 1973), as pingos have a similar spacing to that of the mounds, and the pond sediments found at the crest may relate to thin areas in permafrost, allowing rupture and intrusion of sediment. Modern pingos have a core of clear ice, and would have little topographic relief if this melted. Mathews suggested that if the formation of the pingo involved water saturated soil, then positive relief would result.

Mollard (1983) considered what he termed "reticulate and orbicular microrelief patterns" developed on the floors of ancient glacial lakes in many parts of North America. The structures he describes are of lower relief than those of map unit 8, but are probably comparable to those of map unit 9. The scale of patterning is very similar to that described here, with individual components of the patterns measuring 75-150 m across. Mollard (1983) considered several possible origins but favoured either remobilisation of saturated lake sediments following earthquakes or melting of debris rich ice that had been buried beneath lake sediments as these mechanisms are compatible with diapiric structures and convolutions observed in exposures.

Any proposed origin of the hummocks in the Grande Prairie area must explain:-

a. The semi regular pattern of hummocks;

b. Their geographical distribution, close to major rivers, with relief increasing towards river valleys;

c. The fine grained material composing the hummocks;

d. The style of deformation apparent in the few good sections observed;

e. The observations of Mathews (1978), that they were formed subsequent to lake drainage, as indicated by the association with small calcareous sloughs, and shorelines cut on their slopes by a subsequent raising of lake level.

Mass movement processes are the most likely origin of these landforms. The thickness of lake sediments in the areas in which they are formed suggest that buried ice was not a factor in their formation, and the style of deformation is not compatible with such an origin. The data of White (1983) suggested that there is little evidence of a climate suitable for the genesis of pingos at the probable time of their formation. The style of deformation suggests that the landforms were formed by overpressure in strata below the land surface, with these sediments being pushed towards the surface. This might result due to a general down-slope movement of saturated lake sediments following lake drainage. Such clay rich sediments sloping towards river valleys would be prone to slope failure. With a gradual downslope movement, lateral stress would be applied to the sediments, with this stress being greatest at lowest elevations. The sediment could accommodate such stress by lateral movement, but at the lowest parts of the basin such movement would be prevented by stress applied from the other side of the lake basin. Thus the stress can only be accommodated by vertical movement. This would explain the distribution of the landforms, as well as the style of deformation. Such mass movement processes might be expected to result in parallel arcuate ridges rather than discrete mounds. Further work is required to test this hypothesis.

10. Ridged silt and clay (fLp/ rRr)

Map unit 10 is found in one locality only (northwest of Fitzsimmons, UTM reference 11 U MM 0535) and constitutes only a small fraction of the map area

It is recognised on photographs as a series of ill-defined low concentric lineations, 0.5-1 km long, oriented broadly east-west, convex to the south. It was not examined on the ground or in section.

Geomorphology and genesis

Without firm evidence it can only be speculated that these lineations mark a series of thrusts in the bedrock, masked by a blanket of glaciolacustrine sediment. The tonal patterns of the surface sediment resemble the surrounding map units, suggesting that a blanket of glaciolacustrine silt and clay is present.The pattern of lineation resembles that of ice thrust bedrock described by Moran *et al.* (1980). The orientation of lineation is transverse to the interpreted direction of ice flow in the area (Mathews 1980). Ice thrusting of bedrock has been recognised in one section to the south of the Saddle Hills (8.7.6).

11. Pitted silt and clay (fLk)

Map unit 11 is widespread adjacent to the Wapiti and Smoky Rivers and constitutes approximately 5% of the map area. It resembles map unit 5 on aerial photographs, with dark, even tonal values but differs in the presence of an irregular dark mottling. This mottling is caused by small depressions, filled by small ponds and bog. The unit is composed of laminated silt and clay, with rarely a thin veneer of very fine sand at the surface (Figure 11).

The unit is invariably associated with map unit 5 (silt and clay plain), and map units 16 (sand hummocks) and 17 (sand ridges), forming a transitional zone between them. It is usually found west of occurrences of map units 16 and 17.

Geomorphology and genesis

The bulk of the surface sediment composing map unit 11 was deposited in a glaciolacustrine environment. Because of the close association with map units 16 (sand hummocks, interpreted as dome dunes) and 17 (sand ridges, interpreted as parabolic dunes), the irregular depressions are considered to be caused by deflation of the exposed lake bottom after drainage by wind. The pits are analogous to blowouts described by many authors (e.g. McKee 1979, Brookfield 1984), and are caused by selective erosion of small areas subsequent to removal of vegetation cover or breakdown of a resistant surface layer. Initial small sites of erosion are selectively enlarged. This interpretation is substantiated by the occasional presence of fine sand of probable aeolian origin at the surface. Subsequent to the cessation of aeolian activity the depressions became the site of small ponds, and have been partially filled by organic silt, clay, and peats.

12. Silt and clay veneer over bedrock and diamicton fLv/ dM+dL

Map unit 12 is widespread, constituting 2% of the map. It is recognised on aerial photographs by its dark uneven tones. On the ground it takes the form of a transitional zone between map units 5, 6, 8, and 11 (units largely composed of fines, and interpreted as resulting from glacial lake deposition) and map units unaffected by glaciolacustrine deposition. In these zones the topography conforms to that of the material unaffected by glaciolacustrine deposition, whether it be hummocky diamicton, ridged diamicton, or rolling diamicton and bedrock. At the boundaries of this map unit concentrations of stones are observed at the ground surface, some aligned along prominent benches. In section the map unit consists of a veneer of silt and clay, with some coarse clasts and diamicton interbeds, overlying diamicton. Rarely, poorly sorted sand and gravel is found overlying diamicton close to the margins of the mapped unit.

Map unit 12 has a definite altitudinal control on its distribution, being found at elevations no higher than 840 m overall. This altitude marks the limit of the unit south of the Saddle Hills but the unit is found no higher than about 710 m north of the Saddle Hills (Figure 7).

Geomorphology and genesis

Map unit 12 marks the palæoshorelines of glacial lakes. In these areas, the lake was shallow, and little deposition took place. The glaciolacustrine sediment cover is thus thin, and the topography of the underlying material still discernable. The margin of glacial lakes is by definition relatively high compared to the rest of the lake basin. As discussed earlier, most glaciolacustrine deposition is by sediment gravity flows of various forms, and thus the margins will receive little sediment. Glaciolacustrine deposition in these areas will take place early in the history of the lake, when the retreating ice is close and acting as a relative topographic high, and a source of sediment gravity flows. Most of the sediment in this marginal zone is thus characteristic of ice proximal deposition, with many ice rafted clasts and diamicton interbeds deposited by sub-aquatic debris flow. The water is shallow in marginal areas, exposing sediment to the effects of wave and wind generated currents, keeping fines in suspension, and winnowing deposited sediment. Wave action and lake ice can also have an erosive effect. This causes a washed zone close to the shoreline, where fines have been removed causing a concentration of coarse clasts at the surface.

This action can also develop pronounced wave-cut benches, and in rare cases, deposition of sand and gravel in beaches. Benches interpreted as wave cut are found throughout the area at the margins of this map unit, both within the unit, and developed in adjoining units. Jones (1961) noted beaches and wave cut benches north of Beaverlodge at altitudes between 805 m and 825 m, and less well developed strandlines at 730 m and 700 m (Figure 7). The best developed strandlines in the area are located on the Birch Hills to the northeast of the map area, where four well defined benches lying between 655 and 710 m altitude are present. These are presumed to be identical to the "Lake Rycroft" shorelines (Mathews 1980). On aerial photographs, the benches can be traced over more than 10 km on the north and east of the Birch Hills. In section (sections 28.7.17, 28.7.18) the lowest bench is found to be cut into shale bedrock, and a cut through an upper bench shows 0.5 m well sorted granule gravels, with a medium sand matrix, bedded with beds dipping at 10° to the east. This overlies a minimum thickness of 0.5 m of diamicton. Other sections showing similar characteristics include 25.6.7 (benches lying between 810 m and 835 m on the southwest slopes of Saskatoon Hill); 1.7.5, at 690 m on Kleskun Hill; and 2.7.7., south of the Saddle Hills at an altitude of 825 m, where poorly sorted gravels are exposed on a poorly defined bench (Figure 7).

Also associated with this unit, and too small to map as individual units are occurrences of well sorted sand and gravel, which are interpreted as marking deltas formed by minor streams entering the glacial lake (e.g. section 25.6.8. consisting of well sorted sand at an altitude of 840 m on Saskatoon Hill; 25.7.5. at 820 m to the south west of the Saddle Hills; 7.7.10 at 825 m, south of Demmit to the west of the Saddle Hills; and 24.7.5. at 780 m,north of Sexsmith).

By combining the observations of strandlines and deltas, two major glacial lake levels can be defined. The first (highest) level is marked by beaches, benches, and deltas between 810 and 840 m, and is restricted to the area south of the Saddle Hills. The second is marked by strandline features lying between 655 and 710 m both north and south of the Saddle Hills.

The poorly defined nature of most of the strandline features recognised in the area, combined with multiple strandlines related to each phase makes any assessment of isostatic tilt impossible. Mathews (1978, 1980) suggested that shorelines in the Charlie Lake area, northwest of the 83M map sheet, generally dip at 0.4 m/ km to the east, and north at 0-0.4 m/ km, indicating that isostatic recovery was dominated by removal of Cordilleran ice. However, Tokarsky (1967) measured the dip on a single well defined shoreline in the Grimshaw area as being 25' in 16 miles, dipping to the southwest.

The relative lack of well developed shoreline features may be attributed to:-

i. a resistant substrate, making erosion difficult;

ii. extensive ice cover inhibiting wave action;

iii. unstable lake levels, resulting in only a short period in which shoreline features might develop;

iv. shorelines in the area being protected from prevailing winds and wave action.

The first hypothesis above cannot be supported in this area, as substrates are generally soft and susceptible to erosion. The second, that of extensive ice cover, is plausible, and the third, postulating fluctuating unstable lake levels is considered likely. This would be expected, as an ice margin terminating in water is inherently unstable, and can change position rapidly through the action of calving, unless it is has stable anchor points (Powell 1984, Meier 1987). The multiple strandlines observed also suggest instability. The final suggestion is dependent on the aspect of shorelines with regard to prevailing winds. The lake margin as defined in Figure 7, has a variety of aspects, and preferential development of strandline features dependent on orientation of the shoreline is not observed.

13. Ridged sand and gravel (fLv/ gGr)

This is a minor unit in the map area, being recognised at only three locations. On aerial photographs it appears as light toned. On the ground it forms a low ridge. In one section (30.7.7) it is found to consist of poorly sorted clast supported gravels, with clasts up to 30 cm long axis. The matrix is mainly fine sand, but ranges from fine to coarse.

Geomorphology and genesis

The coarse grained sediments and ridged topography suggest that this unit was deposited in minor esker systems or as kames during ice retreat. The poor exposure prevents any detailed sedimentologic interpretation. The examples recognised here are found where the lacustrine cover is relatively thin, and are probably draped by a veneer of clay and silt, not exposed in section.

14. Complex sand and gravel (sGm + gGc/ dMr)

Map unit 14, is found in one location only, covering about 20 square kilometres in the area of Kamisak Lake. It is found above the known level of glacial lakes, and is surrounded by map unit 4 (ridged diamicton). On aerial photographs it shows varied but dominantly light tones, with a semi-regular mottling. (Plate 7). West of Kamisak Lake the topography consists of irregular rolling hills. East of the lake there is a complex pattern of lineation, with a

Plate 7:- Aerial photograph Alberta Government AS 2313-8, 10 of map unit 14, Kamisak Lake region. Scale bar represents 2 km.

continuation of flutes oriented southwest northeast from the surrounding map unit 4, but cross-cut by a distinct north-south lineation, marked by wide sinuous depressions and lakes. Poor exposures at sections 6.7.6 and 6.7.7 show poorly sorted, crudely-bedded clast-supported gravel, consisting mainly of well rounded quartzite, with subordinate chert, pink and red granite, grey granite, and chlorite schist.

Geomorphology and genesis

The light tones combined with the limited section information suggest that this unit consists largely of sand and gravel, probably deposited in a glaciofluvial environment. The southwest-northeast lineation was inherited from the underlying unit, and is due to fluting by ice moving out of the mountain front. The north-south lineations probably represent channels in glaciofluvial outwash. The appearance of the unit does not resemble an outwash plain or sandur, and has no clear braiding of channels. It is possible that the unit was deposited as ice contact gravels, with a series of ice marginal channels. The oriented lakes parallel lineations over the Saddle Hills, interpreted by Mathews (1980) as marking the flow of Laurentide ice. They may thus be meltwater channels carrying water southward from Laurentide ice. Following glacial retreat, these channels have become filled with silt, clay, and peat.

The cutting of the fluted terrain indicates that this unit was deposited subsequent to the events causing the flutings.

15. Terraced sand and gravel sFt+gFt

Map unit 15 is found adjacent to major modern rivers in the area, and shows light tones on aerial photographs. On the ground it consists of a series of terraces lying above the level of the modern river. Numerous well exposed sections are found in gravel pits throughout the area. The sediments exposed are dominantly well sorted clast supported pebble and cobble gravels, with clast long axes up to 30-40 cm. The gravels are mainly quartzites, well rounded, of moderate sphericity, with lesser amounts of chert, granite, coal, concretionary ironstone, and sandstone. The sedimentary structures are varied, with rough horizontal bedding commonly seen, and, less commonly, clast imbrication and cross bedding. Gravel beds generally constitute 70-90% of the sequences exposed, with sand strata as the other main component.

Geomorphology and genesis

This unit consists of post-glacial fluvial terraces of the Peace, Wapiti, and Smoky Rivers. The environment of deposition of the sediments is comparable to that of the modern rivers, which show both meandering and braided reaches. The preponderance of gravel suggests that flow velocities and discharge might have been generally higher.

No detailed levelling or geomorphological work was performed on terraces in this study, but examination of aerial photographs suggests that two sets of paired terraces can be recognised on the Wapiti and Smoky Rivers, separated by 25 to 30 m, and the lower between 15 and 45 m above the level of modern rivers.

16. Hummocks and veneer of sand sAh+ sAv/ fLp

Map unit 16 is recognised on aerial photographs by light tones, and regular mottling. On the ground, it takes the form of low mounds or hummocks, 1-5 m high, 10 to 25 m diameter, with generally flat inter-mound areas. Spacing between mounds is regular. The hummocks consist of fine sand and silt, and sections through inter-mound areas show a veneer of fine sand and silt over laminated silt and clay. One exposure through a hummock (section 16.6.8) shows large-scale cross beds, dipping at low angles. Prominent concentrations of calcium carbonate around decayed roots cut sedimentary structures. Large hummocks contain well sorted fine to medium sand, with few fines (Figures 14 and 15)(Halsey 1989). Smaller hummocks, and veneers of sand are generally finer grained, with significant quantities of silt and some clay. The unit is confined to the margins of unit 17 (ridged sand) and associated with unit 11 (pitted fines).

Geomorphology and genesis

The origin of these sand hummocks is the subject of a detailed sedimentologic study (Halsey 1989). They are considered to be aeolian dome dunes, as defined by McKee (1979), associated with a sand sheet or veneer (Fryberger *et al.* 1979). They are developed on a silt-clay substrate deposited in a glaciolacustrine environment. The glaciolacustrine sediments in the area of this unit contain very little sand and it seems unlikely that they were the source of the material composing the larger dunes. The proximity to major rivers suggests that high level terraces provided the bulk of sediment composing these landforms. The deflation pits of map unit 11 may indicate some supply of sediment from glacial lake sediments. This sediment may form the minor dome dunes, and sand veneer as these contain a high proportion of silt, and minor clay. Sand sheets are normally composed mainly of sand and the veneer recognised over much of this area is finer, and less well sorted than most examples described (e.g. McKee 1979, Fryberger *et al.* 1979, Kocurek and Neilson 1986) .

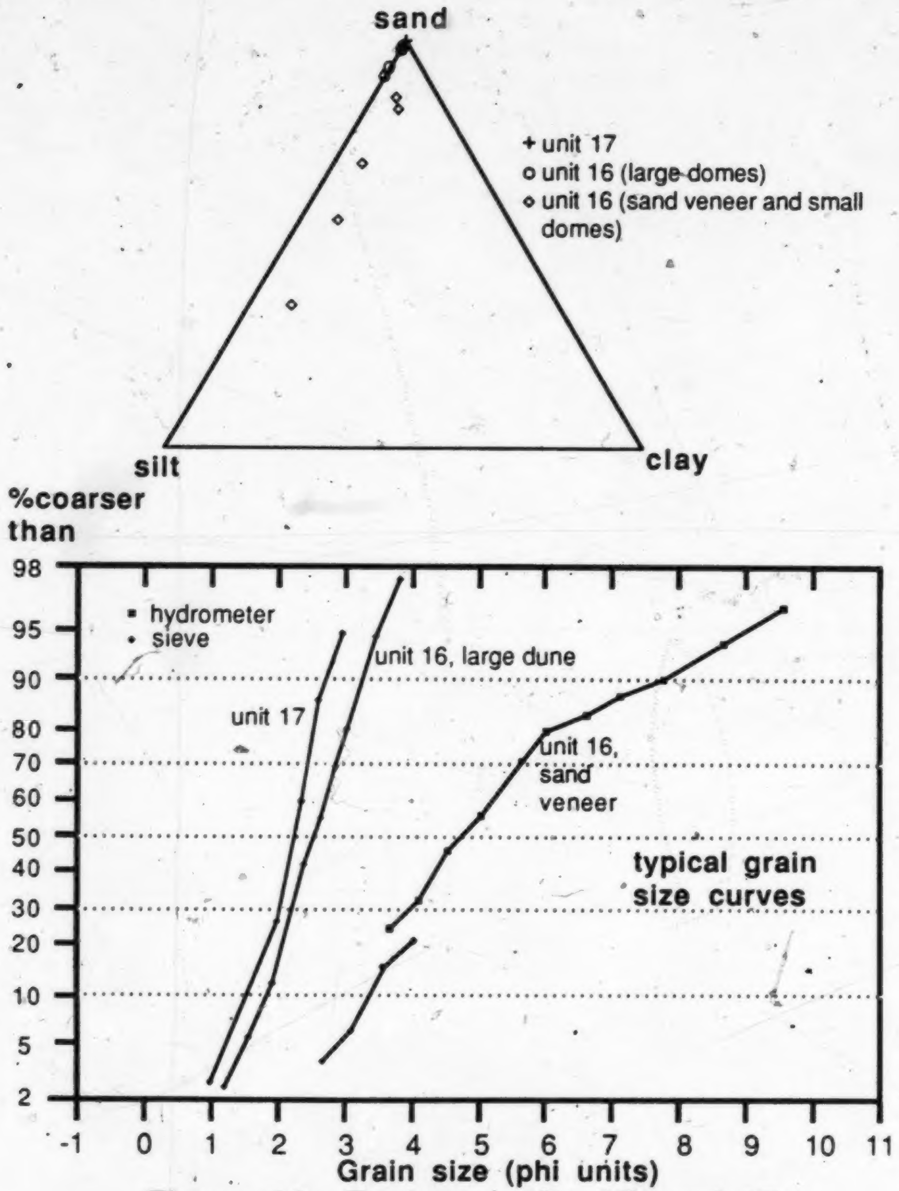
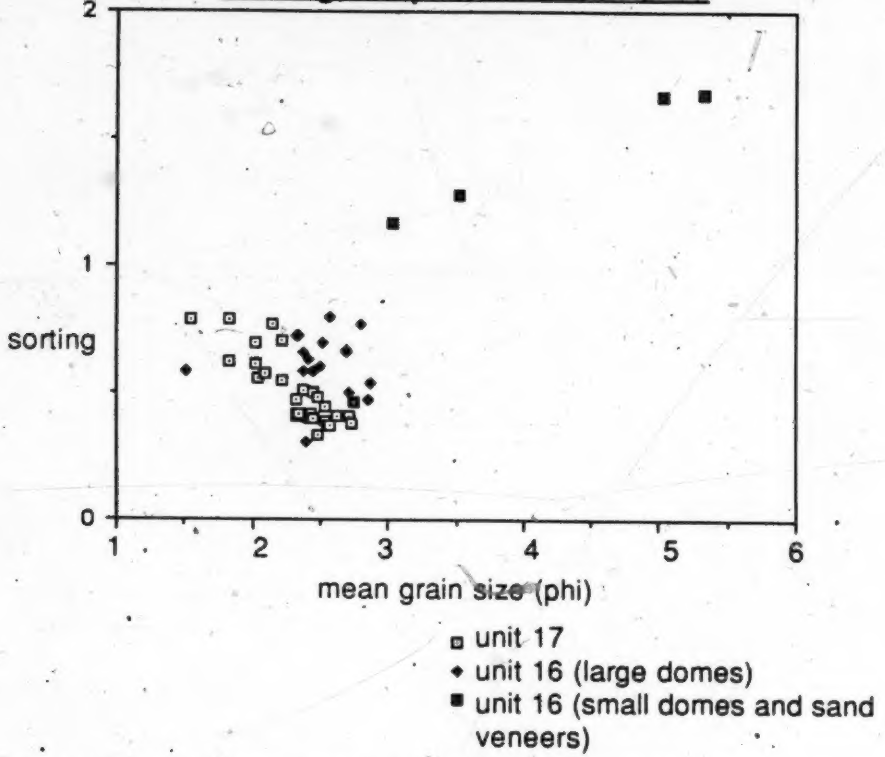


Figure 14:- Texture, units 16, and 17

Data from Halsey (1989)

Figure 15:- Plot of mean grain size against sorting, map units 16 and 17



Grain size statistics calculated by the methods of Folk and Ward (1957), from the data of Halsey (1989).

Without well exposed sections map unit 16 may be confused with map units 8 and 9, as the topography and grain size are very similar. The only area of the map sheet where adequate sections did not exist is the broad zone west of the Smoky river in the Bezanson area. It was mapped as map unit 16, due to the proximity of other units deposited by aeolian action, but it is possible that it should have been mapped as map unit 8.

Included in map unit 16 is an area of low relief, without a distinct mounded topography, found at the top of the Peace River valley northwest of Dunvegan. The surficial material here consists of very fine sand and silt. This area probably consists of "clifftop loess" , an aeolian deposit caused by wind channeled up and over a valley side, which dropped its sediment load as it reaches the valley top (c.f. David 1977, Catto 1983).

17. Ridged sand over gravels and silt and clay sAr/ fLp+gFt

Map unit 17 is distinguished on aerial photographs by elongate and U shaped oriented light toned ridges, with dark toned inter-ridge areas (Plate 8). On the ground the map unit consists of sharp crested ridges up to 20 m high, regularly spaced, on a flat to rolling plain, with irregular depressions containing small ponds or marshes. In numerous sections, the ridges are found to be composed of well sorted fine to medium sand. Sedimentary structures are well exposed in section 30.6.2., which is dominated by planar tabular cross bedding of various forms. A detailed description of this section may be found elsewhere (Halsey *et al.* 1987, Halsey 1989). Grain size analyses show well sorted fine and medium sand with little silt or clay (Figures 14 and 15).

The sediments between ridges are composed of organic deposits and silt

Plate 8:- Aerial photograph Alberta Government AS 2312-238, 240 of parabolic dunes of map unit 17, north of Wapiti River, west of Pipestone Creek. Lacustrine silt and clay of map unit 5 lies north of the dune field. Scale bar represents 2 km.

and clay deposited in small ponds and lakes (identical to map unit 20, but impossible to differentiate on the scale used to map).

Geomorphology and genesis

These sediments are also the subject of a detailed sedimentologic study (Halsey 1989) and so the details of their formation will not be discussed here. The landforms in the area south of Grande Prairie have been discussed by Odynsky (1958) and David (1977), and the sand ridges identified as parabolic dunes, indicating a palaeowind direction from the west. Parabolic dunes are characteristic of temperate climatic conditions, and it has been suggested that both vegetation and moisture play important roles in their formation (Odynsky 1958). David (1977), Halsey *et al.* (1987), and Halsey (1989) provided evidence that moisture is the primary control on the morphology of such dunes, with sediment supply also important. Jones (1961) and David (1977) suggested that the source of sediment for the dunes of the Grande Prairie fields was glaciofluvial outwash. There is little evidence of such sediments exposed in the Grande Prairie area, and it is suggested that a more likely source is the high level terraces of the Wapiti and Smoky Rivers.

18. Scarped diamicton dCx+ rCx

Map unit 18 is found along major river valleys and constitutes less than 1% of the map area. On photographs, it is recognised by the characteristic semi-circular scars of rotational slumps. On the ground it has steep irregular slopes along major river valleys. In section it shows variable characteristics. Section 19.7.6, in a gravel pit adjacent to the Peace River at Dunvegan, shows terrace gravels overlain by a colluviated sequence showing clasts of diamicton in a sand matrix, overlain by a diamicton containing many clasts of complexly folded laminated silt and clay. In other sections, unit 18 usually takes the form of diamicton containing abundant modern roots and wood aligned on horizontal planes. Grain size analysis shows these diamictons to be clay rich and sand poor.

Geomorphology and genesis

This unit is formed by remobilisation of previously deposited sediment. The dominant mechanism of mass movement in the area is that of rotational slumping. The slump scars of major slumps are prominent on aerial photographs forming a distinctive fingerprint pattern. The slumps affect areas as much as 2 kilometres from the edge of river valleys. The sediment composing this unit is a complex mixture of diamicton, laminated silt and clay, and disturbed bedrock. Diamictons observed in section appear to be a mixture of disturbed lacustrine and glacigenic material. It is likely that numerous small debris flows have occurred in addition to rotational slumping, and in some cases these have been observed at the tail of small modern rotational slumps. This mechanism is probably responsible for the mixing of sediment types seen in section.

The scale of major slumps suggests that the locus of failure might be in the bedrock. Most of the large rotational slumps are observed in the north of the map area, along the Peace and Smoky Rivers. The bedrock in the valley walls in these areas is shale of the Smoky Group, whereas in the south of the map area, the walls are composed of sandstone and shale of the Wapiti Formation. Shales of the Smoky Group contain a high proportion of expandable clays (Jones 1966), making them susceptible to mass movement. Mathews (1978) suggested that major slope failures are related to the presence of pre-glacial sorted sediment in areas where the modern river valleys intersect pre-glacial channels. This is supported in part by the distribution of these features in the 83 M map area.

Atterberg limit determinations (Figure 10) show that both diamictons and laminated silt and clay may also be prone to failure on steep slopes. Numerous small scale rotational slumps are observed in the Grande Prairie area, mainly involving glacial lake sediments. It is considered , however, that the scale of major slope failure is such that it must be due to bedrock failure or failure in pre-glacial sediments rather than in the comparatively thin glaciolacustrine and glacigenic diamicton cover.

19. Modern alluvium gFc+sFp

Map unit 19 is found at the base of modern river valleys, and forms less than 1% of the map area. It consists of the modern river channels themselves, and flat lying areas adjacent to them. Sections were not described in detail but observations of cutbanks show sand and gravel overlain by silt.

Geomorphology and Genesis

The modern rivers in the map area consist of deeply incised channels, showing both meandering and braided reaches. At low water the channels can be braided, and some braid bars have been stabilised by vegetation. The depth of incision means that there are no extensive flood plains. Overbank deposits are found on low terraces above the modern river, and consist of fine sand and silt. Large volumes of sediment are contributed to the system by mass movement, with the toes of rotational slumps often constricting the main channel of the Smoky River. The slump sediments are eroded, and fines subsequently winnowed by current action.The channels therefore contain considerable amounts of coarse sediment, derived locally from diamicton.

Such a fluvial system does not fit readily into facies models outlined by Walker and Cant (1984), but is intermediate between the sandy braided and sandy meandering fluvial systems. Point bars do exist where the modern river is not constricted by the valley walls, and it would be expected that vertical accretion deposits would be found at the top of a fining upward sequence. Generally the constriction of the valley sides means that point bars are rare, and the bulk of the sediments found are sand and gravel.

20. Organic deposits pOp+cLp

Throughout the low lying part of the map area, depressions up to 10 km in diameter contain standing water, and bog. On aerial photographs marshy areas are prominent, showng dark even tones. To the east of large lakes (Bear Lake in particular), a series of lineations paralleling the shoreline is clear. On the ground, map unit 20 is found in rounded depressions, generally lying only a few metres below the prairie surface. The unit was not observed in section. The largest area mapped in this manner is a large depression north of Kleskun Hill, east of Sexsmith. To the east of this depression is a prominent bench oriented roughly north-south, visible on aerial photographs, which has a relief of approximately 5 m when examined on the ground.

Geomorphology and genesis

Topographic lows result in pooling of water, and lacustrine deposition. The origin of these lows is unknown. It is possible that they represent the sites of ice blocks slow to melt following deglaciation, but it is more likely that they are simply the result of topographic lows in the bedrock. As the depression fills, aquatic vegetation becomes established, resulting in deposition of organic sediment, and further infilling to form a marsh or swamp. The sediments of filled depressions are thus mainly organic peat, with some silt and clay. Those with standing water probably have a larger clastic component in the sediments.

There is some evidence of variation in level of these lakes. The raised beaches to the east of Bear Lake indicate that the lake formerly stood 5-10 m above its present level. Dawson (1881) showed a lake (named Kleskun Lake) north of Kleskun Hill, in the location of the large depression mentioned above. Although the disappearance of this body of water may be due in part to drainage by farmers, the height of the bench to the east suggests that at some time during the Holocene, changes in the ratio of precipitation to evaporation resulted in a greater water level in this lake. Jones (1961) mentioned raised beaches of La Glace Lake, and reported the opinion of local residents that the lake has receded drastically in recent years, following clearance of the surrounding forest cover. Although the change in lake levels may be due to a change in climatic conditions, it seems likely that clearance of natural vegetation cover would increase evaporation and snow melt, and result in less run-off reaching the lakes. The timing of lake level flucuations is unknown, but would test this hypothesis.

Other geomorphic features

in this section, three other geomorphic features of the map area which are not mapped as individual map units will be discussed.

Ice thrusted bedrock

Evidence of glaciotectonic action is only clearly seen in one locality, section 8.7.6., near Homestead at the foot of the Saddle Hills (Appendix 1) . Sections are well exposed in silage pits dug into a prominent bench, about 5 m high. The sections consist largely of sandstone and shale, overlain by diamicton on the north margin of the section where it is up to 2m thick.The bedrock generally dips to the north and is folded and faulted (Plate 9). The sandstone and shale show differing styles of deformation. The sandstone is faulted and fractured, in places appearing brecciated. The central part of the section displays steeply dipping shale beds which appear to have maintained cohesiveness. The dips of beds decline along section to the south, varying from from 58° northward at the centre to flat to 1-2° at the southern edge.

Ice thrusting of bedrock is common on the western prairies (Moran *et al.* 1980). The poorly consolidated nature of the bedrock means that it is easily incorporated into over-riding ice. The style of deformation seen in this example suggests that the shales reacted to stress by deforming plastically and folding into tight folds, whilst the sandstone deformed by brittle fracture.

The orientation of structures in the exposure is a good indication of ice flow direction suggesting ice flow to the south. This can be compared with fabric measurements at section 86.13/ 8.7.7., located 150 m to the east. Unless there was considerable local variability in ice flow patterns, there is some disagreement between the two methods in interpreting ice flow direction, as the modal clast orientation is 30-40° east of that predicted by ice thrust orientations. It is possible that the orientation of thrusting was controlled to some exent by weaknesses in the bedrock, particularly as the strike of bedrock in the area is roughly east-west.

Meltwater channels

Meltwater channels are not prominent in the area. A poorly defined channel

Plate 9:-Ice thrust bedrock, section 8.7.6, near Homestead. Inferred ice flow was from left to right of the picture.

exists in the Birch Hills at an elevation of 690 m (UTM reference 11U MM 190700). Several potential meltwater channels were identified on aerial photographs in the Saddle Hills, but were not major features. A distinct channel was recognised in the vicinity of Demmit (Figure 7).

Jones (1961) describes linear depressions in the vicinity of Poplar Hill, northeast of Beaverlodge. Drilling showed 15 m of granule gravel overlain by diamicton and lake clays. The stratigraphic evidence suggests that such channels might have been formed during advance, rather than retreat, as the gravels are overlain by diamicton. Jones (1961) considers the diamicton to be slumped into channels formed during deglaciation.

Similar linear depressions have been noted elsewhere in the map area, northwest of Kakut Lake (UTM 11U MM 005660), and at the outlet of Clairmont Lake (Figure 7). In the absence of stratigraphic evidence, it can only be speculated that these mark meltwater or ice marginal channels formed in the early stages of deglaciation prior to the establishment of glacial lakes.

Patterned ground

Patterned ground is seen on aerial photographs in three localtities in the east of the map area (Plate 10). The patterning consists of hexagonal and pentagonal polygons, with a diameter of 150-200 m, developed on a substrate of glacial lake sediment. They were not examined on the ground or in section.

Henderson (1959) described similar polygons east of the Grande Prairie sheet, and suggested that they are due to ice wedge formation. The size of these polygons is considerably greater than that commonly found in areas of active permafrost today, where polygons average 30-40 m diameter (Washburn

Plate 10:-Aerial photograph Alberta Government AS 2315-144, 146 of possible remnant ice-wedge polygons north of the Smoky River. Scale bar represents 2 km.

1973). However, Henderson cites rare cases of polygons up to 200 m diameter. Similar polygons can occur through dessication cracking of clay and silt, but are much smaller.thamn those observed here (Washburn 1973).

Support for post-glacial periglacial conditions is found in two sections (20.6.5 and 3.7.7, locations given in Appendix 1) in the south of the map area. 20.6.5 shows well sorted sand overlying poorly exposed diamicton. The contact between the two units is sharp, and forms a V shape. Stones along the contact are oriented vertically and no internal structures are visible. The "V" is about 40 cm wide at the top, thinning to zero at a depth of 60 cm. Such a structure may be a fossil ice wedge cast although the evidence is equivocal. Section 3.7.7 shows a similar contact between sands and diamicton, but is less well exposed.

If these patterns did arise as a result of ice wedge formation, then it would follow that climatic conditions were considerably colder than present at some time following deglaciation. Palaeoenvironmental interpretations do not indicate conditions significantly colder than present in the Holocene (White 1983), and thus if periglacial conditions did exist, it must have been shortly after the drainage of glacial lakes in the area.

CHAPTER 3:-STRATIGRAPHY AND SEDIMENTOLOGY -

STRATIGRAPHIC UNIT A

In the following chapters the stratigraphy and sedimentology of Quaternary deposits in the Grande Prairie region will be discussed. After defining a basic stratigraphic framework, each major stratigraphic unit will be discussed in detail. No formal designation of stratigraphic units is made but the units are identified on the basis of lithology, and are thus lithostratigraphic.

Stratigraphic framework

Examination of sections throughout the map area suggests that six major stratigraphic units can be defined in the study area. They are, in order of deposition:-

Unit A- Gravel, sand and silt containing no Laurentide provenance material. This unit is identified by the absence of Laurentide clasts, and its stratigraphic position, over bedrock and below glacigenic sediments.

Unit B- Gravel and sand:- this unit is identified by the presence of Laurentide clasts, and its stratigraphic position, below massive diamicton.

Unit C-. Diamicton:- this unit is identified on the basis of its lithology and geometry, consisting of a thick tabular deposit of diamicton

Unit D- Laminated silt and clay:- this unit is identified by its lithology and stratigraphic position, overlying stratigraphic unit C.

Unit E- Gravel and sand. This unit is identified by its Laurentide clast provenance, its geomorphic association (usually found in terraces of the modern river channels), and its stratigraphic relationships (overlying diamicton and laminated silt and clay).

Unit F:- sand and silt. This unit is identified by its lithology (well sorted sand and silt), its geomorphology (well defined ridges and domes), and its stratigraphic position (overlying stratigraphic units D and E).

Each unit will be described separately, and the environments of deposition and probable age discussed.

Unit A:- Gravel, sand and silt, with no Laurentide provenance material

Sediments are identified as pre-glacial if they lack granitic and gneissic clasts derived from the Canadian Shield. This assumes that the area was unaffected by mountain ice, so strictly these sediments should be identified as being deposited prior to glaciation from the northeast. It is difficult to identify clasts diagnostic of mountain glaciation, as the regional slope is down from the west, and fluvial systems also transport clasts of Cordilleran lithology to the area. Stratigraphic position confirms the interpretation of pre-glacial, with the sediments usually overlying bedrock, and underlying diamicton of Laurentide provenance interpreted as being glacigenic.

Locations

Sections containing sediment of this unit are comparatively rare. Figure 16 marks the location of sections in which these sediments have been identified, and Table 6 gives brief section descriptions. Two sections exposed along the Simonette and Beaverlodge Rivers are particularly well exposed and will be described in detail.

Simonette River Section

This section is located on the Simonette River in the southeast of the map area (section numbers 16.6.1/ 86.5-Appendix 1). It has been briefly discussed in Bobrowsky *et al.* (1987), and Liverman *et al.* (1988, 1989).

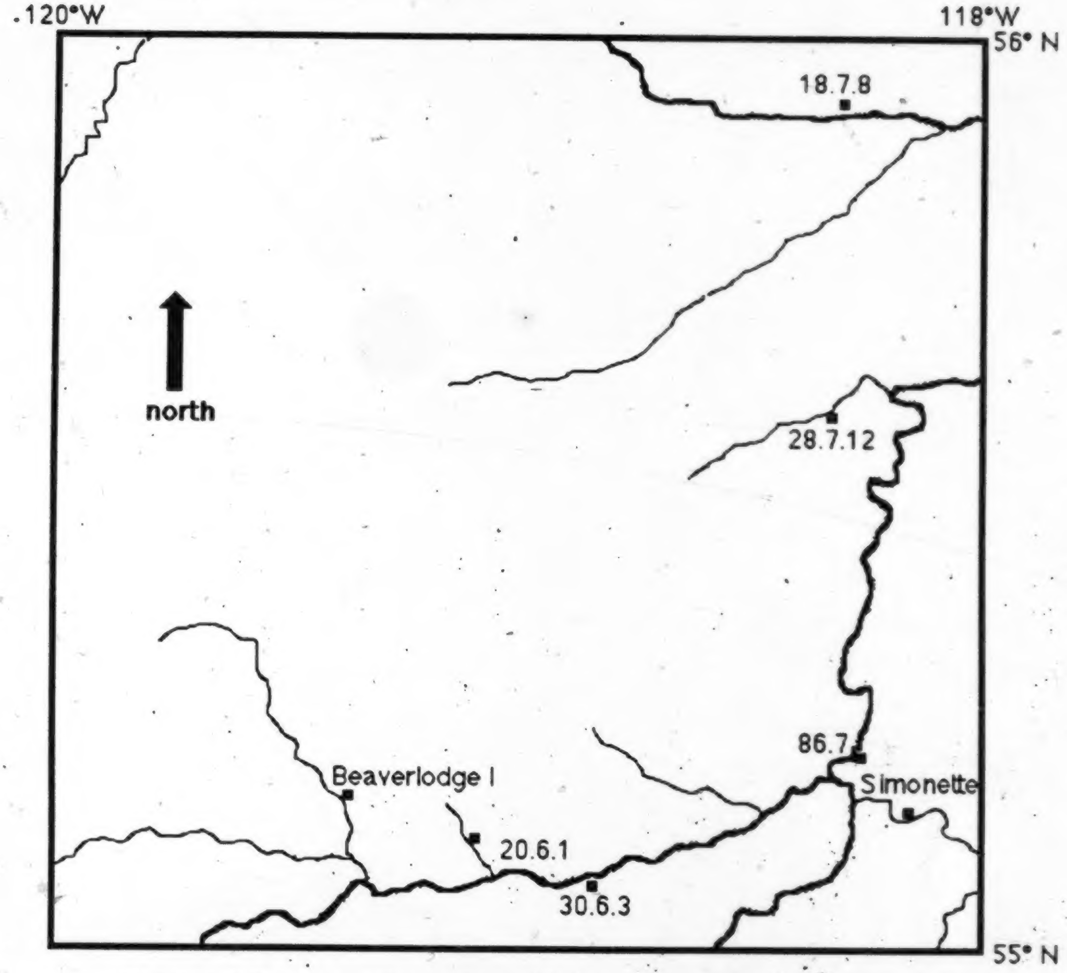

120°W
118°W
56° N
55° N
north
18.7.8
28.7.12
86.7
Simonette
Beaverlodge I
20.6.1
30.6.3

Figure 16:- Location of sections showing stratigraphic unit A

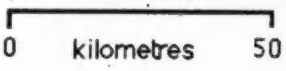

0
kilometres
50

Table 6:- Sections through stratigraphic unit A

This table lists and briefly describes sections which show sediments identified as belonging to stratigraphic unit A. Elevations of base of units are estimated from 1:50,000 NTS maps and are approximate.

Section number	Elevation	Stratigraphy
Simonette River	540 m	coarse gravel 2-3 m thick, successively overlain by 2.5 m interbedded sand and gravel; 1-2 m imbricated pebble and cobble gravel; and 12 m of interbedded sand, silt, and clay.
86.7	525 m	2.5 m quartzite pebble gravels, overlain by 8m+ fine and medium sand, flat bedded and cross laminated. Over this is a 12 m covered interval, and 8 m of fine sand and silt, flat bedded and cross stratified.
28.7.12	540 m	Overlying shale and sandstone bedrock are 3 m of poorly bedded quartzite gravel, interbedded with trough cross beddded medium to coarse sand, followed by 8 m or more of interbedded silt, sand, and clay. Following a 15 m covered interval, 10 m of diamicton is exposed
18.7.8	512 m	4 m gravel, overlying sandstone bedrock, and overlain by 8 m sand with thin gravel interbeds, and poorly exposed diamicton.
30.6.3	565 m	2 m or more poorly sorted clast supported gravel, overlying shale bedrock
20.6.1	625 m	1.5 m gravel overlain by diamicton
Beaverlodge River I	655 m	3 m gravel, overlain by 0.5 m sands, then glacial gravel, and diamicton

It is exposed over approximately 75 m horizontally, and 30 m vertically on an east-west oriented cutbank.The Simonette section is divided into 4 major units (SR-1 to SR-4, Figure 17).

Unit SR-1:- Gravel

Description

Unit SR-1 consists of poorly sorted, clast supported, cobble gravel overlying 5 m of Wapiti Formation shale. The base of the unit shows a lag of boulders and cobbles, with a maximum diameter of 90 cm. Most of the clasts are cobbles, with long axes between 10 and 15 cm. The unit is roughly horizontally bedded, with laterally discontinuous beds 0.5-1 m thick. The clasts are well rounded, of moderate sphericity, and consist mostly of quartzite with rare chert, coal and sandstone. Two clast fabrics from this unit show bimodal distributions with strong east-west and weaker north-south alignments. The matrix consists of poorly sorted medium sand dominated by quartz, with subordinate chert, ironstone, and coal. Heavy mineral separations show an assemblage dominated by limonite and hæmatite, with minor hornblende and pyroxene. Some biconvex lenses of sand and silt occur within the unit. Abundant wood fragments were recovered from one such lens, 35 m from the west end of the section and 1 m above the contact with bedrock. The contact with unit SR-2 is gradational.

Interpretation

This unit is interpreted as being a moderate to high energy fluvial channel deposit. The generally coarse grain size indicates rapid flow conditions, and the poor sorting rapid deposition and variable flow. The coarse lag at the base of the unit marks the base of a major channel, and the geometry of the basal

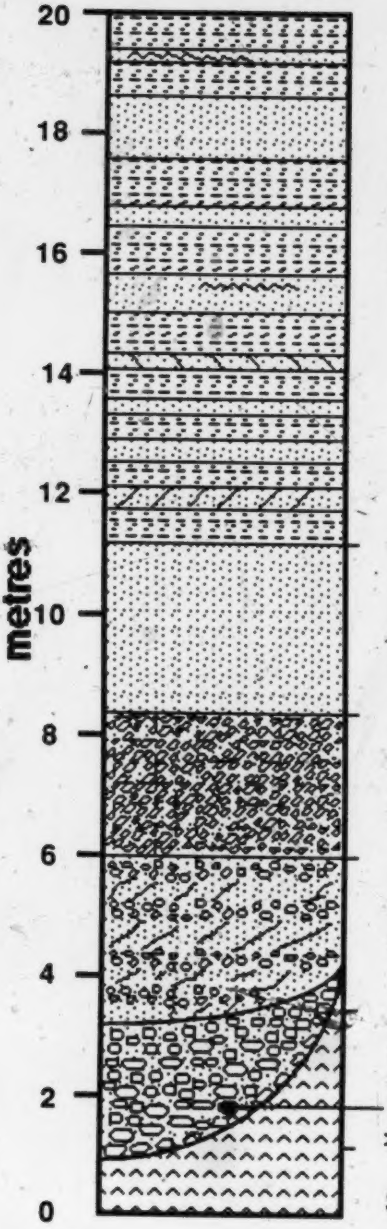


Figure 17:- Stratigraphic column, Simonette Section

Unit SR-5:- interbedded massive fine-medium sand, cross-laminated fine to medium sand, cross-bedded medium sand, massive silt, and horizontally laminated silt

Unit SR-4:- massive fine to medium sand

Unit SR-3:- imbricated pebble gravel

Unit SR-2:- interbedded pebble gravels and cross bedded sands

Unit SR-1:- cobble gravels with lag wood, 37, 010± 2690 BP (AECV-428C), >51,000 B.P. (GSC-4623 HP),

Shale bedrock, Wapiti Formation

contact suggests a confined sedimentary system. The discontinuous nature of beds, and the rare finer lenses show lateral migration of major channels, with sand deposition in lower flow conditions in minor channels. The clast lithology and sand mineralogy indicates that the unit was deposited prior to Laurentide glaciation in the area.

Unit SR-2: Interbedded sand and gravel

Description

Unit SR-2 consists of 2.5 m of interbedded pebble gravel, and cross-bedded fine to coarse sand. The gravel is moderately sorted and clasts are well rounded, with a modal clast diameter of 7 cm and a maximum of 15 cm. The gravel beds are clast supported with a medium to coarse sand matrix. The clast lithology is mostly quartzite with lesser amounts of chert, coal, and sandstone. The gravel is roughly bedded, with beds 30-50 cm thick, and forms 70% of the unit. Sand beds are planar tabular cross-bedded with foresets dipping generally westward but showing considerable variation. Sand mineralogy is mainly quartz, with common lignite and ironstone, and rare chert. Rare interbeds of cross laminated fine sand and silt show flame structures, and drape underlying gravel clasts. Cross laminae indicate eastward current flow. Unit SR-2 thins to 0.6 m to the east. The contact with unit SR-3 is gradational.

Interpretation

The generally finer grain size indicates a decline in flow conditions to moderate to low energy. The alternation of sand and gravel suggests flow conditions were variable. Unit SR-2 can be interpreted as marking either a regional decline in gradient, or a local effect caused by migration of the main channel. The variable thickness of the unit, and the transition upwards into coarser sediments suggests that the latter interpretation is correct. The fine grained sediments would be deposited during low flow conditions in minor channels. Flame structures indicate rapid loading of saturated sediment, probably by re-occupation of minor channels causing deposition of coarser sediments. Overall, Unit SR-2 appears to have been deposited in a fluvial system which showed many minor channels, considerable channel migration, and variable flow conditions.

Unit SR- 3: Imbricated pebble gravel

Description

Unit SR-3 consists of well sorted pebble gravel with minor sand interbeds. Gravel clasts are mostly 3-5 cm in diameter, with rare clasts up to 15 cm diameter, and are well rounded. Their lithology is dominantly quartzite. The gravel is roughly bedded, and the clasts are commonly imbricated, dipping to the west. The gravel is clast supported with a fine to coarse sand matrix. The upper contact with unit SR- 4 is sharp.

Interpretation

Unit SR-3 marks a return to more rapid flow with imbricated gravels being developed in channel bars within a major channel. The relative lack of fine grained sediments indicates that subsidiary channels were minor components of the system. The unit was probably deposited when a major channel migrated laterally.

Unit SR- 4: Interbedded sand and silt

Description

This unit consists of 12 m or more of interbedded sand and silt. Access to the upper part of the section is poor; thus sedimentologic description is limited, and the unit could not be sub-divided. At the base, 3 m of massive and flat bedded fine to medium sand, silt, and clay is exposed. Overlying this appears to be mostly horizontally bedded fine to medium sand and silt, with some laminated and cross laminated clay and silt beds, cross bedded medium sand (with foresets dipping west), and massive silt. Beds are generally 2-50 cm thick, and there are no coarse clasts found. Heavy minerals from sand strata are mainly hæmatite and limonite, with minor pyroxene and hornblende. Fragments of wood are found associated with sand strata.

Interpretation

The decrease in flow conditions suggests a history of channel abandonment, with periodic re-occupation. Sand was deposited during intermittent flow during high water and flood events, but the bulk of the sediment is silt and fine sand, deposited by low flow and suspension settling. The mineralogy of the sand indicates that the unit was deposited prior to Laurentide glacial influence in the area.

Summary

The sedimentary system depositing this sequence is thought to be a moderate energy braided stream. The sediments provide evidence of variable flow conditions, channel migration, variable flow direction, and a general fining upwards reflecting a decrease in energy. Variable flow directions and conditions are characteristic of the braided stream environment (Miall 1977). Proximal high energy braided streams are dominated by gravel, with little sand or silt . The sediments described here resemble the deposits of a moderate energy distal system, such as the Donjek type of Miall (1977). Such systems deposit gravel in the main channel reaches, but also have areas adjacent to the main channel where sand deposition takes place in minor channels, and inactive tracts on the margin of the main system, where deposition is largely by vertical accretion of fine sediment, with sand and gravel deposited in channels during flood events (Williams and Rust 1969). The typical sequence arising from migration of the main channel would thus be gravel at the base, fining upward through sand to silt and clay (Rust and Koster 1984). This strongly resembles the sequence exposed at this location. Thus the sediments show a history of channel migration and abandonment.

Current direction indicators are variable but show a mainly westward flow. Examination of the map of Carlson and Hackbarth (1974) shows the section to be located in a prominent east- west oriented bedrock channel, a tributary to the Bezanson channel. Clast lithology from gravel, and sand mineralogy indicates that the sediments were deposited prior to Laurentide glaciation of the area.

A piece of wood with attached bark, 15 cm long and 1.5 cm diameter, was collected from a silt lens in unit SR-1. It yielded a radiocarbon date of 37,010±2690 B.P. (AECV-428C); a fragment of wood from the same location had an aspartic acid ratio of 0.115 (UA-2400). Re-dating of wood fragments (identified as being *Abies*, H.Jetté, Quaternary Palaeoecology Laboratory, Geological Survey of Canada, personal communication) from the same locality in a high pressure counter yielded a date of >51,000 B.P. (GSC-4623 HP). The original date was considered to be finite, although close to the limit for that laboratory (personal communication, L.D.Arnold, Alberta Environmental Centre), but possibly should have been considered infinite. Detrital wood being deposited in a fluvial environment may represent a mixture of recent and reworked older wood. It is possible that the assemblage at this site consisted of wood of a variety of ages, with the fragment dated as AECV-428C being relatively young. The larger sample consisting of multiple fragments dated as GSC-4623-HP might then consist of a mixture of younger and older reworked wood. Given this evidence, it is not possible to make a definite age assignment to the unit other than it is Middle Wisconsinan or older.

Sections 86.7 and 28.7.12, show broadly similar sequences to the Simonettė River section, although less well exposed, as does the section at Watino described by Westgate *et al.* (1971, 1972), and Liverman *et al.*(1989). All show a general fining upward trend from gravel to fine sand and silt, with no evidence of Laurentide provenance material. Sections 86.7, 28.7.12, and the Watino section are all located within the Bezanson bedrock channel (Carlson and Hackbarth 1974), and were probably part of the same fluvial system (Figure 5). Generally the elevation of the sections is compatible with this interpretation (Table 6). Section 28.7.12 is apparently higher than would be expected and may represent an earlier terrace of the system. The base of the Watino section is at an altitude of 390 m, and the gradient of the Middle Wisconsinan fluvial system between 86.7 and Watino can be estimated to be 2.8 m/ km, slightly steeper than the modern gradient of 1.9 m/ km.

The radiocarbon dates of Westgate *et al.* (1971, 1972), and Liverman *et al.* (1988a, 1989) support a Middle Wisconsinan age for this system. The palaeoenvironmental interpretation of Westgate *et al.* (1971, 1972) was of a fluvial/ oxbow lake developed in a climate similar to the modern. This interpretation is consistent with that given here, of channel abandonment in a moderate to low energy braided system.

Beaverlodge River I Section

This section is located on the Beaverlodge River, south of Beaverlodge.

The section shows 18 m of sediment, exposed laterally over 50 m. Bedrock is not exposed in this section but is seen at river level 400 m to the south. The section shows gravel at the base, overlain by diamicton and laminated silt and clay (Figure 18). The discussion here will be limited to the basal gravel.

The lowest exposed unit at the section consists of moderately to poorly sorted pebble gravel. The clasts are mostly well rounded quartzites of moderate sphericity, with some chert, and rare angular sandstone and concretionary ironstone. The matrix consists of coarse to fine sand, and constitutes 30% of the unit. The clasts show a pronounced vertical orientation (Plate 11), and no bedding is apparent. Vertically oriented wedges or lenses of sand and silt, with rare vertically oriented clasts cut the unit, thinning downward. The largest example has maximum horizontal dimensions of approximately 2 m and extends for over 2 m vertically. Poorly defined horizontal bedding is apparent at the top of this wedge and faint steeply dipping internal lamination is visible (Plate 11). The upper contact of this unit is sharp and truncates underlying structures.

To the north of the exposure, the overlying unit consists of gravel of Laurentide provenance, and the geometry of the contact is that of a channel. On the south end of the exposure the basal gravels are overlain by massive diamicton, with a horizontal contact.

The basal gravels are considered to be pre-glacial on the basis of the absence of Laurentide provenance clasts. In this exposure the colour contrast between basal pre-glacial gravels and overlying glacial gravels is pronounced. The section lies within the Wembley bedrock channel of Jones

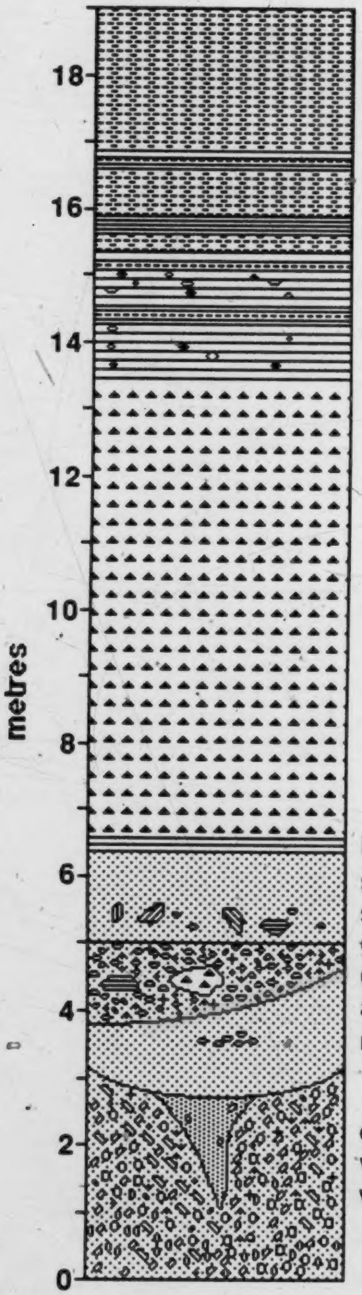

18
16
14
12
10
8
6
4
2
0
metres
massive silt and clay, no clasts or intraclasts
interbedded laminated silt and clay, and massive silt
laminated silt and clay, common coarse clasts and intraclasts
massive diamicton
laminated silt and clay
sand with intraclasts of laminated silt
gravel with common granitic clasts, intraclasts of diamicton and laminated silt
medium sand with gravel lens
quartzite gravels, poorly sorted, vertical clasts common, silt/ sand wedges

Figure 18:- Stratigraphic column, Beaverlodge River I section

Plate 11:-Beaverlodge River I section, possible ice wedge cast. Shovel is 1 m long.

(1961, 1966) (Figure 5). The disturbance of primary sedimentary structures makes a detailed interpretation of environment of deposition difficult. On the basis of the position of the section and the grain size of clasts, it is suggested that the sediments were deposited in a moderate to high energy fluvial system.

The common vertical clasts, and the distinct wedge structures indicate that the sediment was subjected to a periglacial climate. Vertical clasts are oriented by intense freeze-thaw action and are typical of periglacial environments (Washburn 1973). The wedge structures are interpreted as ice wedge casts, suggestive of permafrost. Thus at some time prior to burial these sediments were subject to a climate much cooler than the modern.

The age of these gravels is unknown, but is probably pre-Late Wisconsinan, as the section lies to the west of the Simonette River and Watino sections. The altitude of the deposit indicates that it may well be related to the Simonette section, as the river gradient interpreted from this assumption would be approximately the same as the modern river system. The sequence exposed suggests a higher energy system than the modern Beaverlodge River. Periglacial conditions might be related to the advance of Laurentide ice into the area in the Late Wisconsinan. Such a climate may well have existed earlier in the Quaternary, however, related to either mountain ice advance, or Laurentide advance that did not reach the area.

Section 20.6.1. shows a poor exposure of coarse gravel and also lies within the Wembley channel (also described by Jones 1961, 1966). It was probably deposited in the same fluvial system as the gravel in the Beaverlodge River I section.

Discussion-Stratigraphic unit A

Pre-glacial sediments are rarely exposed in the 83M map sheet, but are probably common in the sub-surface along the line of bedrock channels. Examples were found in the Shaftesbury, Bezanson, and Wembley channels, as well as in smaller tributary channels (Figure 5). The thickness of these sediments is variable, reaching a maximum in section of 30 m of gravel, sand, and silt. They were deposited in a moderate energy fluvial environment, probably braided. It is suggested, on the basis of radiocarbon dates from Watino and the Simonette River section, that the deepest period of fluvial incision was during the Middle Wisconsinan. It is likely that the general west to east drainage pattern was established from the Tertiary onwards (Mathews 1978), and the Middle Wisconsinan river system marked the culmination of a long period of continuous fluvial activity.

The basal gravels contain coarse, well rounded quartzite clasts as channel lags, probably too coarse to be moved by the Middle Wisconsinan fluvial system. Jones (1961, 1966) suggests that these clasts have been reworked from Tertiary gravel. Examples of high level gravel of similar grain size and lithology are common to the south of the map area, where they are found on flat topped hills well above present river valleys. Thus it is possible that such deposits existed over the 83 M sheet and were reworked into the fluvial system.

Tokarsky (1967) recognised three topographic levels of pre-glacial gravels in the Grimshaw area, and suggested that the higher levels were earlier terraces of the fluvial system. Such deposits were not definitely identified in the Grande Prairie region although section 28.7.12 may represent such a higher level terrace. A more detailed study of sections along the Smoky River, which often intersects the pre-glacial Bezanson channel, may reveal a long history of fluvial deposition.

The major stratigraphic implication is that there has been no Laurentide glaciation in the area prior to the Late Wisconsinan. Such a result is surprising in light of the complex history of Laurentide glaciation on the Prairies stretching back 2 million years reviewed by Fenton (1984).

CHAPTER 4:-STRATIGRAPHY AND SEDIMENTOLOGY - STRATIGRAPHIC UNIT B

Stratigraphic unit B consists of sand and gravel of Laurentide provenance, underlying diamicton. It is comparatively rarely exposed in the map area.

Location

The unit is only well exposed in the Beaverlodge River I and II sections. These will be discussed in detail below.

Beaverlodge River I

Description

The location and basic description of this section is given above (Figure 18). A 2 m thick unit of horizontally stratified and trough cross-bedded gravel overlies sediment interpreted as pre-glacial and is distinguished from it by the presence of numerous clasts and matrix material derived from the Canadian Shield. The gravel is poorly to moderately sorted, with a maximum clast diameter of 10-15 cm and an average clast diameter of 5 cm. It is clast supported, with a matrix of medium to coarse sand. The clasts include well rounded quartzite, angular granite, and gneiss, with minor amounts of chert and coal. Large angular sandstone clasts are also present. Intraclasts of diamicton forming lenses up to 1 m long are frequent, and rare clasts of laminated clay were observed. A sharp contact leads into two well defined beds of sand, a total of 50 cm thick. The lower of the two beds consists of coarse to medium sand, roughly bedded, with some pebbles. Many angular clasts of laminated silt and clay up to 30 cm diameter are found and show diverse orientation, from flat-lying to vertical. Bedding in the sand drapes these clasts. The upper bed contains fewer intraclasts, and consists of roughly bedded fine sand. Overlying these beds, and separated from them by a sharp contact, is at least 3 m of extensively faulted and folded diamicton containing intraclasts of laminated clay. These units are laterally discontinuous, and, 20 m south along section, pre-glacial gravels are directly overlain by massive diamicton.

Interpretation

The clast lithology indicates that these units either post-date or are synchronous with initial Laurentide glaciation. The units stratigraphically underlie massive glacigenic diamicton of Laurentide provenance (see stratigraphic unit C below), and thus were deposited during glacial advance into the area, sub-glacially, or folowing a minor retreat. The flow velocity suggested by the sediment is generally less than that interpreted for the underlying pre-glacial gravels, and declines up-section. The presence of clasts of Laurentide provenance in diamicton intraclasts indicates that the intraclasts were derived from glacial ice or reworked from till. Such clasts would not survive fluvial transport over any great distance, and thus it would seem likely that the ice margin was close at the time of deposition if they were derived directly from it. Such clasts have been observed in glaciofluvial sediment deposited sub-glacially, where they are dropped from the tunnel roof following melt-out (Vivian and Bocquet 1973; Levson and Rutter 1986). They might also result from reworking of debris flows from the ice margin or previously deposited till and thus be deposited pro-glacially. Intraclasts of laminated silt and clay were deposited in a quiet water environment dominated by suspension settling. They were either ripped up from their original stratigraphic position by a drastic increase in flow; or slumped into the channel containing the gravel after deposition; or frozen and rafted by seasonal river ice.

Two models can explain the properties and stratigraphic position of these sediments. They may have been deposited by sub-glacial fluvial activity, with diamicton being dropped in from the tunnel roof, or alternatively, they may be the result of pro-glacial fluvial action, with diamicton being derived from debris flows or reworked till. The channel geometry of the deposit is less likely in a sub-glacial setting, where erosion of overlying ice rather than underlying sediment takes place, resulting in a positive topographic feature (Rothlisberger 1972). The upper contact seen here is sharp and flat. In a sub-glacial setting, this could occur if ice re-advanced after stagnation, eroding and truncating the glacio-fluvial sediment. In a pro-glacial model, such a contact would be expected as ice advanced over the sediments. In a sub-glacial environment, laminated silt and clay intraclasts may have been derived from a sub-glacial pond, or from low energy deposition in a sub-glacial tunnel. In a pro-glacial setting, it is likely that glacial lakes would form in front of advancing Laurentide ice (which dammed regional drainage). Such lakes would contain laminated silt and clay. For silt and clay intraclasts to form, such lakes would have to drain, and their sediments eroded by a glaciofluvial system. Silt and clay might also be deposited in abandoned channels or as overbank deposits.

The overlying diamicton in this section shows evidence of considerable colluviation. The upper sand beds with laminated silt intraclasts may have formed post-glacially with mass movement of post-glacial lake sediment bringing laminated silt and clay into a fluvial system. The sequence appears conformable, however, and post-glacial mass movement is considered unlikely. Although there is insufficient evidence to make a definitive interpretation, the sequence is thought to have originated in a pro-glacial fluvial sedimentary environment during an advance phase of the Laurentide ice sheet. This proposal is consistent with the basic sedimentary features and the stratigraphic relationships of the units.

Beaverlodge River Section II

This section is located on the Beaverlodge River, north of Beaverlodge River section I and southwest of Beaverlodge. It consists of a 15 m high cutbank, exposing sediments over 50 m laterally. The basic stratigraphy is of a complex of gravel, sand, and diamicton, successively overlain by two diamicton units and a thin sequence of laminated silt and clay (Figure 19, Plate 12, Plate 13). Because of their stratigraphic position and clast lithology, the basal units are considered to be representative of stratigraphic unit B.

The upper units are considered to be representative of stratigraphic units C and D and will be described in Chapter 5.

Description

Unit BRII-1:- Description

Poorly exposed at the base of the section is 1.5 m of diamicton, massive at the base, but with numerous stringers and lenses of fine sand close to the upper contact. It is light olive grey in colour (5Y 6/2, dry, fresh surface). The upper contact is gradational and dips at 18° to 170°. Laterally the unit is discontinuous, pinching out into a sequence of interbedded sand and diamicton to the north. Lenses and stringers of sand dip between 15° and 35° to the south. Clasts are mainly quartzite (43%) and locally derived

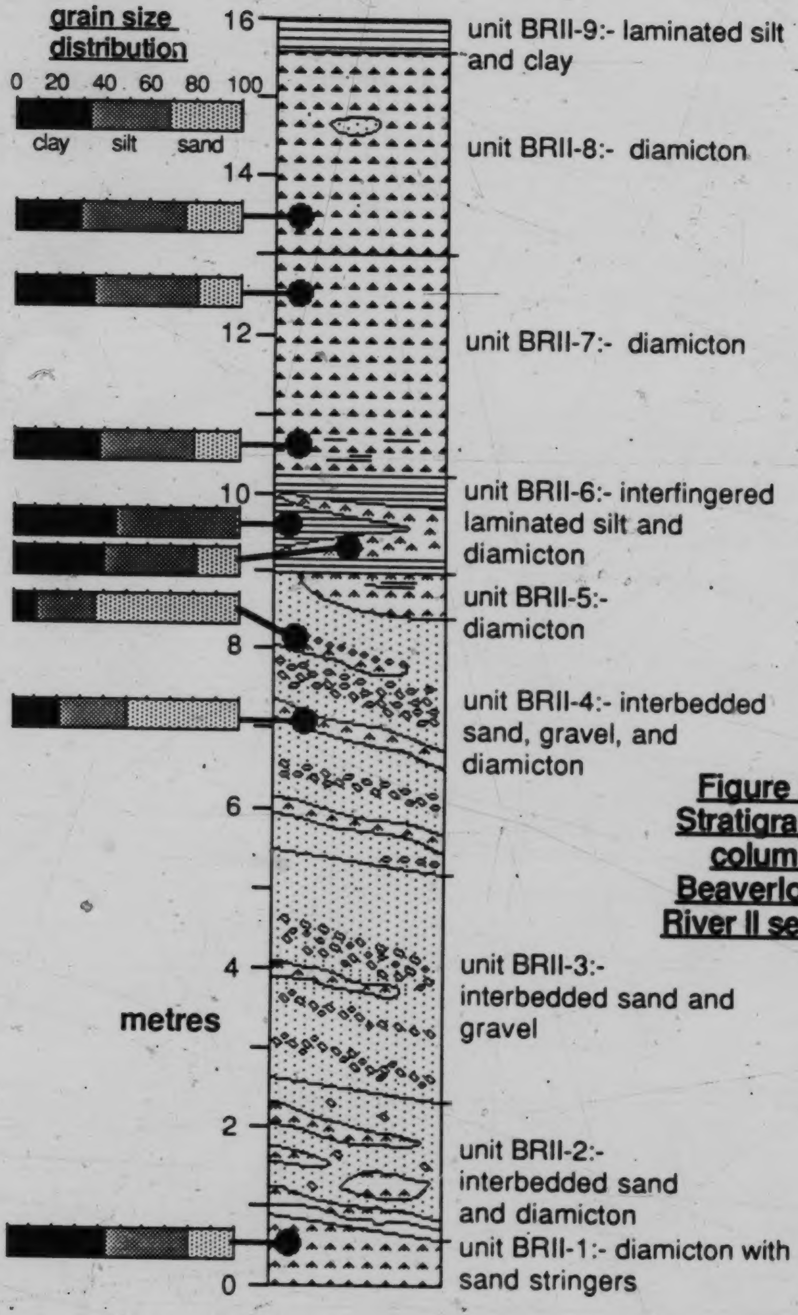

grain size distribution
0 20 40 60 80 100
clay
silt
sand
16
14
12
10
8
6
4
2
0
metres
unit BRII-9:- laminated silt and clay
unit BRII-8:- diamicton
unit BRII-7:- diamicton
unit BRII-6:- interfingered laminated silt and diamicton
unit BRII-5:- diamicton
unit BRII-4:- interbedded sand, gravel, and diamicton
unit BRII-3:- interbedded sand and gravel
unit BRII-2:- interbedded sand and diamicton
unit BRII-1:- diamicton with sand stringers

Figure 19: Stratigraphic column, Beaverlodge River II section

Plate 12 :-Overview, Beaverlodge River II section. Section is approximately 16 m high.

Plate 13:- Basal units, Beaverlodge River II section.

sandstone, coal, and concretionary ironstone (30%). Granites and gneisses derived from the Canadian Shield are also prominent (Appendix 4, Figure 20). The unit is silt and clay rich compared to most diamictons in the study area (Figure 21, Appendix 3). One 25 stone fabric was obtained from this unit and shows a moderate to strong bimodal orientation (S1=0.59), with the principal mode plunging at approximately 16° to 200°, and a secondary mode plunging at 25° to 130° (Figure 22). Modal clast roundness is 0.6, as is modal sphericity (Figure 23).

Interpretation

It is proposed that this unit was deposited as a sub-aerial or sub-aquatic debris flow. Clast lithology is broadly similar to that of overlying diamictons interpreted as glacigenic (see below), but contains a much higher proportion of quartzite. This suggests that the source of material for the flow was glacigenic diamicton. The higher proportion of quartzite is probably due to incorporation of material from surrounding gravels during flow. The clast fabric is moderately oriented and parallel to local slope, as would be expected in a debris flow (Lawson 1979b, 1981, 1982; Mills 1984; Gravenor 1985, 1986).

Unit BRII-2:- Description

Unit BRII-2 is 0.5 - 2.0 m thick, with upper and lower contacts dipping at 10° to 20° to the south. It consists of approximately equal proportions of well sorted medium to fine grained sands and diamicton. The diamicton forms lenses 10-20 cm diameter and 2 -10 cm thick, as well as beds 2- 10 cm thick. The diamicton contains abundant quartzite, sandstone, and granitic clasts. Sands are flat-bedded, with some contortion of beds resembling poorly

Figure 20:-
Lithology histograms, Beaverlodge River II section

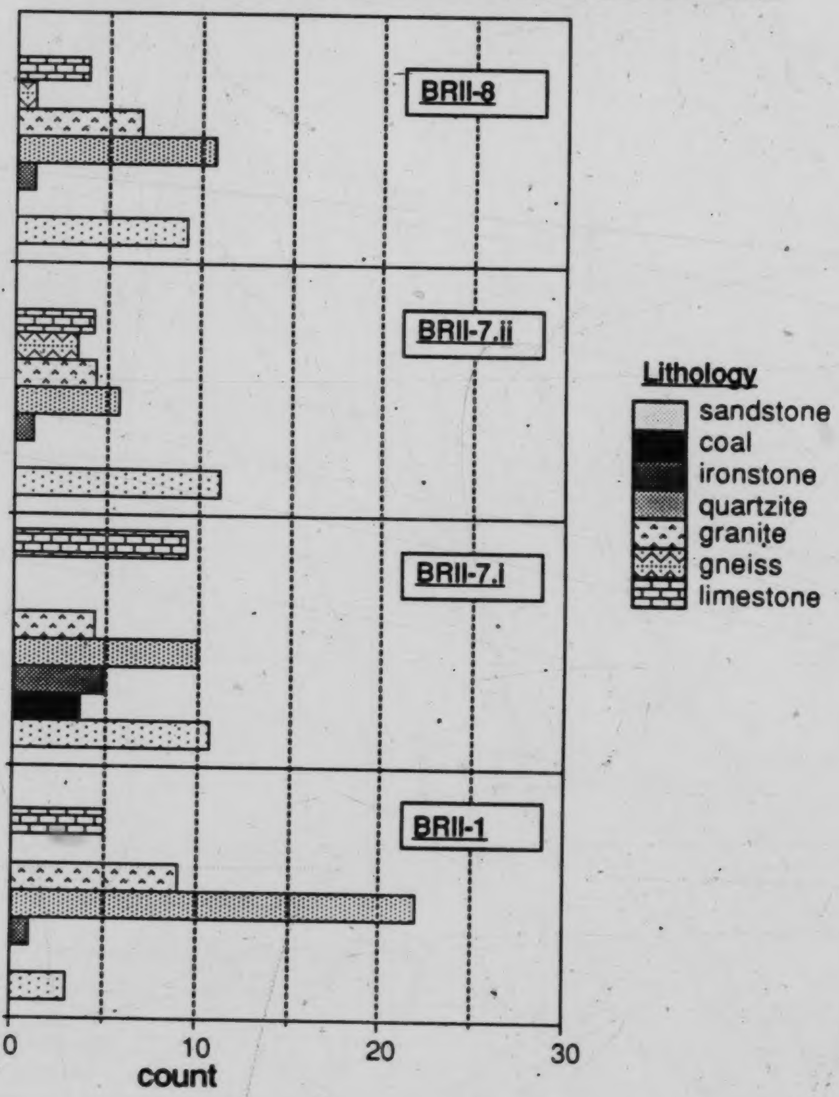
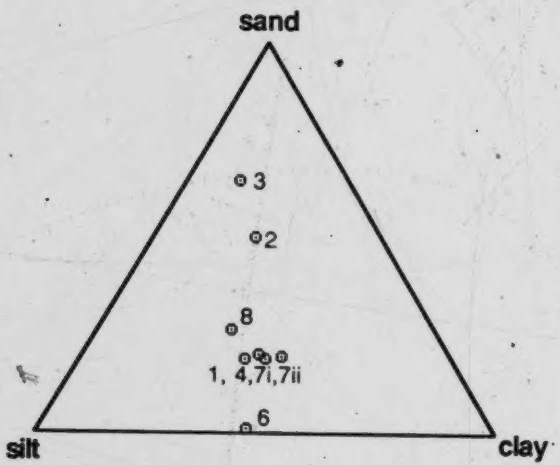
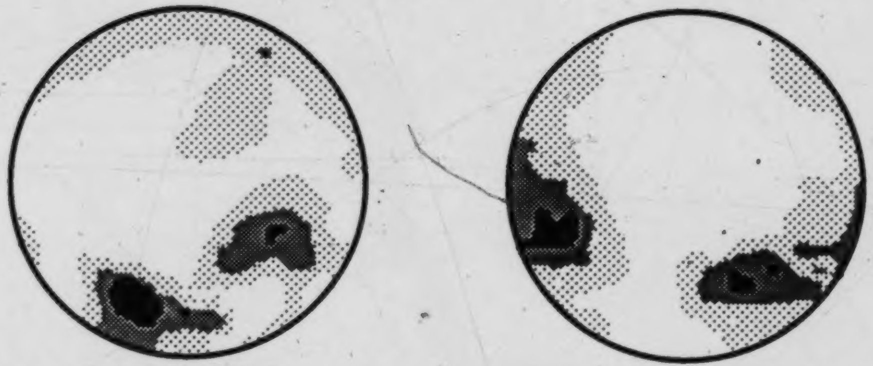


Figure 21:-Ternary plot of grain size distributions, samples from Beaverlodge River II

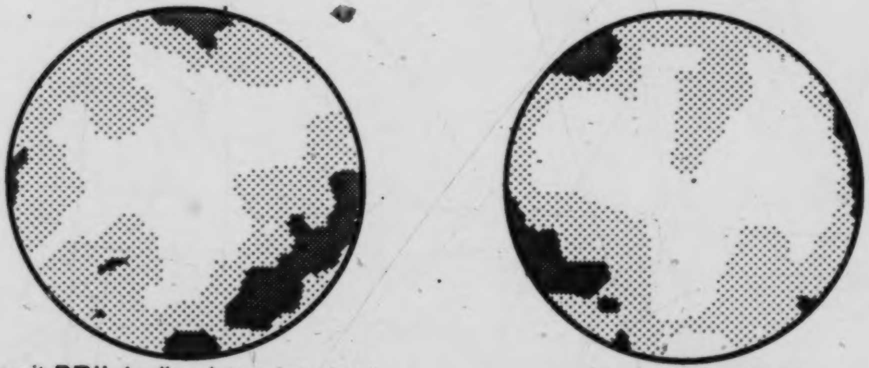


Numbers refer to unit numbers (see text, appendix 3).
All samples are from diamictons, apart from sample 6, which was obtained from laminated silt and clay. See figure 19 for sample locations.



unit BRII-1
S1= .59, 16/181 S2= .29, 28/ 082
S3= .12, 57/ 298

unit BRII-2, diamicton interbed
S1=.58, 11/112, S2=.37, 35/210
S3=.04, 52/ 008

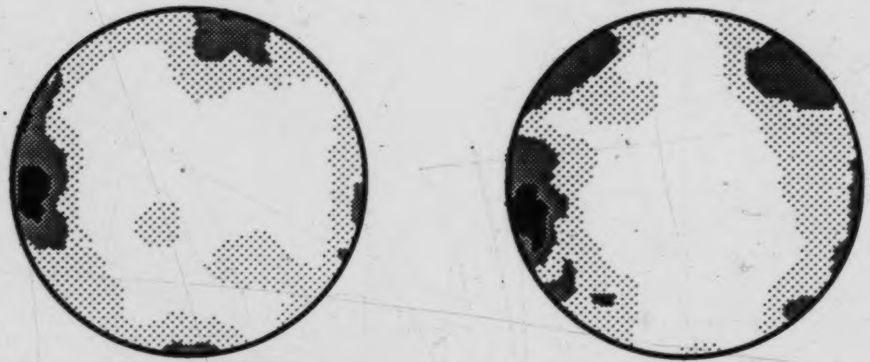


unit BRII-4, diamicton interbed
S1=.50, 14/139, S2=.36, 04/230
S3=.13, 75/337

base, unit BRII-7
S1=.47, 11/246, S2= .37, 05/155
S3=.15 78/040

Figure 22:- Fabrics from Beaverlodge River II section
All fabrics are based on measurements of 25 stones. Fabrics are contoured and eigenvalues calculated using the Orient program of H.A.K Charlesworth, and others, Department of Geology, University of Alberta

contour intervals
□ <4%
▨ 4-8%
▩ 8-16%
■ greater than 16%



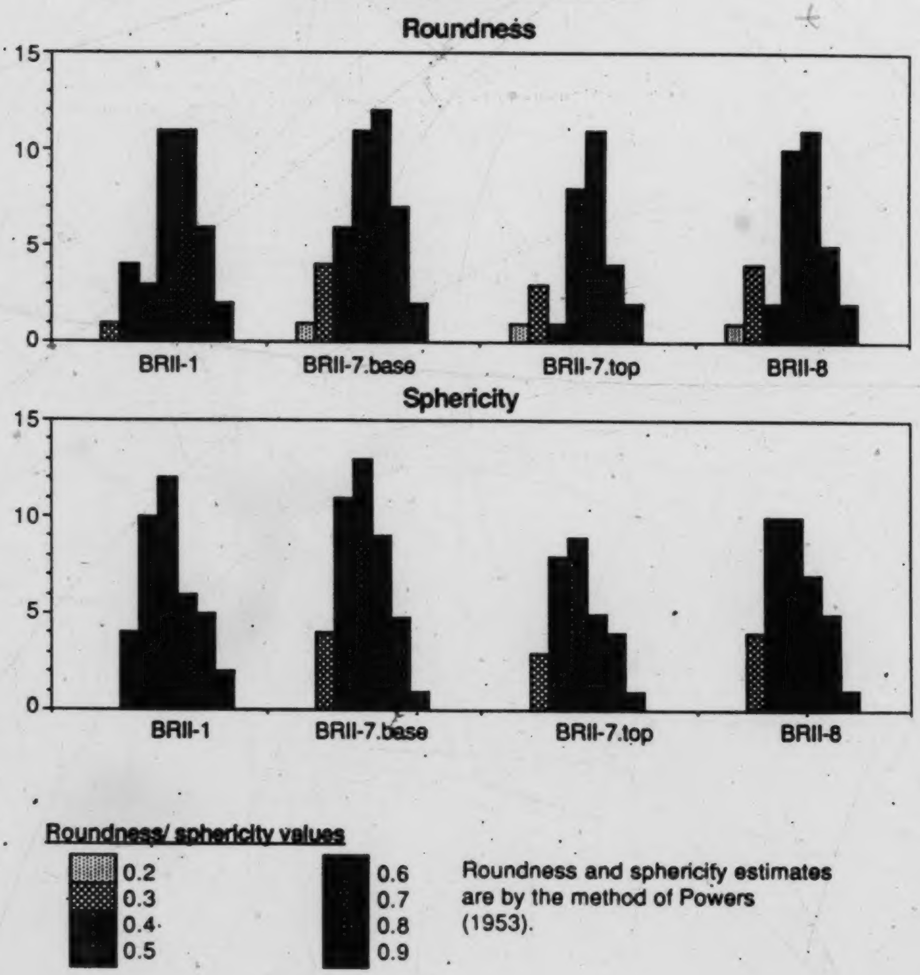
top unit BRII-7
S1=.54, 11/265, S2=.37, 03/356,
S3=.08, 78/099

unit BRII-8
S1= .63, 09/280, S2= .30, 11/352
S3= .07, 76/133

☐ 0
░ 4-8%
▒ 8-16%
■ greater than 16%

Figure 22 (continued):-
Fabrics from Beaverlodge River II section

Figure 23
Roundness/ sphericity estimates,
Beaverlodge River II section



Roundness

Sphericity

Roundness and sphericify estimates are by the method of Powers (1953).

developed flame structures. The sand strata contain rare coarse sand lenses and beds, with abundant coal, and also isolated clasts up to 20 cm diameter which are aligned with their long axes paralleling bedding. Throughout the unit, beds and lenses dip to the south at angles between 10° and 30°. Both upper and lower contacts of the unit are gradational. A fabric was obtained from a single 1 to 5 cm thick diamicton bed and shows a weak to moderate bimodal girdle distribution, with modes at 250 and 150 azimuth. S1 is moderate (0.58) and S3 is low (0.04) (Figure 22).

Interpretation

This sequence of sand, gravel and diamicton is interpreted as showing the influence of both current flow and debris flow during its deposition. The diamicton strata are relatively thin and discontinuous and were probably deposited by debris flow processes. The weak bimodal girdle clast fabric is typical of that found in subaquatic debris flows (Kulig 1985; Gravenor 1985, 1986). The texture of these diamictons is sandy compared to the overlying glacigenic diamictons. The association with current bedded sorted sediment indicates that these debris flows may have been sub-aquatic rather than sub-aerial. The clast lithology and texture suggests that the source of material for the flow is glacigenic diamicton. The sandy texture is due either to winnowing of fines during flow, or incorporation of surrounding sediments into the flow. The dip of the beds is probably a primary depositional feature. The clast fabric from this unit and unit BRII-1 indicates alignment of clasts parallel to the dip of beds, and this suggests that the beds were originally deposited on a southerly dipping palæoslope.

The flat-bedded sands were probably deposited by current flow. Flame structures result from rapid loading of overlying sediment, and may be caused by debris flow, or gravity flow of sorted sediments. Gravel and coarse sand lenses and beds are deposited in channels, or by periodic increases in discharge. Isolated coarse clasts strongly suggest ice rafting. If the dip of the beds is a primary feature, then the environment of deposition may be deltaic, with these beds representing foresets. Such a delta might form sub-aquatically, from discharge of meltwater at the base of an ice front, or sub-aerially. The unit might also be deposited in a sub-aerial pro-glacial fluvial system.

Unit BRII-3:- Description

Unit BRII-3 consists of 2.0 - 5.0 m of interbedded sand and gravel with rare diamicton interbeds. It is distinguished from unit BRII-2 by a lower proportion of diamicton and generally coarser texture. Beds dip at between 30° and 40° to the south and southeast. The basal 1 - 4 m of the unit is predominantly coarse sand and gravel. The gravel is well sorted, with an average clast diameter of 0.5 cm, and a maximum clast diameter of 4-5 cm. Clast lithology is dominated by coal, with common quartzite, granite, and sandstone. Both sand and gravel are mainly planar bedded, but some sand beds show planar tabular cross bedding, indicating current flow to the south. The upper 0.5 m of the unit is flat bedded medium to coarse sand, which has undergone considerable deformation, with many faults and open folds. Rare diamicton interbeds, 2- 3 cm thick and with a sandy matrix texture, are found throughout the unit. The upper contact of the unit is gradational.

Interpretation

Unit BRII-3 was deposited in a similar manner to unit BRII-2. The transition to coarser grain sizes indicates deposition closer to the source of sediment. Well sorted gravel may be deposited by current action or by gravity flow (Lowe 1976, 1984, McCabe *et al.*1984). The absence of well defined normal or inverse grading suggests that current flow was the likely mechanism. Planar tabular cross bedding in the sands suggests moderate energy current flow. Faults and folds may be due to synsedimentary deformation, with instability induced by loading. Diamictons were deposited by debris flows.

Unit BRII-4:- Description

Unit BRII-4 is 3.5 m thick, and consists of interbedded sand, gravel, and sandy diamicton. Most of the basal 2 m of the unit is sand, and consists of well sorted, fine to coarse grained, planar beds and planar tabular cross beds. Diamicton beds are 5-10 cm thick, and grade from clay dominated at the base of the unit to sand dominated towards the top (Figures 19 and 21). Diamicton beds in the upper part of the section rarely show a gradational upper contact into poorly sorted gravel. Beds are laterally discontinuous, pinching out to the south. One fabric was obtained from a single diamicton bed, 0.5 m north of its pinch-out. This fabric shows a poorly oriented multi-modal distribution, with clasts generally flat lying, but also with rare high-angle oriented clasts (Figure 22). The S1 value is low (0.50), and S3 is comparatively high (0.14).

Interbeds of gravel are well sorted, clast-supported granule gravel, with prominent coal fragments as the coarsest clasts. Beds at the base of the unit dip at 20°-30° to the south, and dips decline upwards to 10°- 20°. The upper contact with Unit BRII-5 is sharp.

Interpretation

This unit is thought to have been deposited in a similar manner to units BRII-2 and 3 above. The general decrease in grain size suggests an increase in distance from the source of sediment. Gravel interbeds may be the result of grain flow, caused by remobilisation of proximal deposits. Diamictons are likely deposited by sub-aquatic debris flow. The grading from diamicton to poorly sorted gravel observed is similar to that reported by Visser (1983), who interprets such sediments as being deposited by cohesive sub-aquatic debris flow. This is supported here by the weak fabric, and the lateral pinch-out of the beds. The lithology of clasts indicates that the source of material for the flows is glacigenic diamicton.

Unit BRII-5:- Description

This unit consists of a discontinuous bed of diamicton 0 - 1 m thick that extends 2 m laterally. Its upper contact is sharp and horizontal, whereas the lower contact is sharp and convex downwards. The diamicton is mainly massive, but contains indistinct clay laminae. It is clay rich with few stones.

Interpretation

The geometry, and lateral discontinuity of unit BRII-5, combined with its association with underlying strata suggest that it was also deposited by a debris flow. Clay laminae are either inherited from the source material, or, more likely, deposited by suspension settling. In this case the unit would consist of a series of individual flows, with clay being deposited in the intervals between flows. The absence of sand or silt laminae indicates that deposition was taking place without the influence of current flow in a body of standing water.

Unit BRII-6:- Description

Unit BRII-6 consists of inter-fingered laminated silt and clay, and diamicton. The silt and clay strata are rhythmically bedded and generally flat lying. Each silt-clay couplet consists of a normally graded lamina. Load and flame structures are prominent (Plate 14), as are rare coarse clasts and soft-sediment clasts that deform underlying laminae and are draped by overlying laminae. At the maximum thickness of 20 cm, 24 couplets were counted. The laminae are tightly folded underlying a major diamicton interbed. Diamicton beds are discontinuous and mainly massive, with some clay laminae. One bed, a maximum of 30 cm thick, thins northwards over 10 m, and is divided by a bed of laminated silt and clay, forming two tongues or noses. The lower tongue pinches out over 0.5 m, but the upper can be traced laterally for a further 1.5 m, thinning to 2-3 cm, and becoming laminated. Over 20 m of lateral exposure to the north the laminated silt and clay strata thin and further inter-tongue with diamicton before pinching out completely.

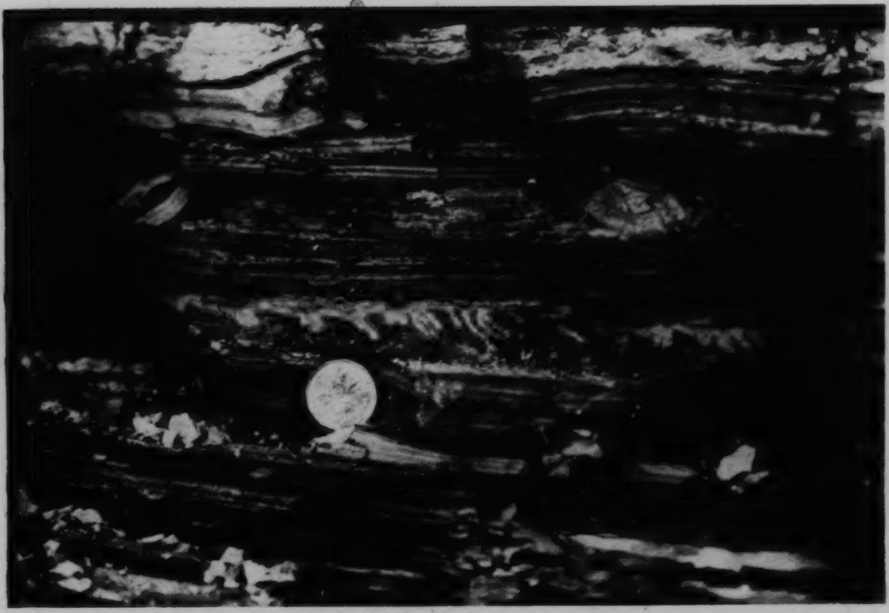
Interpretation

This unit will be discussed in greater detail below, but the presence of laminated, graded clay and silt indicates lacustrine deposition. The presence of intraclasts and coarse clasts further suggests that the environment was glaciolacustrine, with deposition by turbidity currents, and ice rafting of coarse clasts.

Discussion of units BRII-1 to 5

This entire sequence may be considered to be a complex of interstratified sand, gravel and diamicton, deposited in the same environment. The clast lithology clearly indicates that the sequence was deposited in association

Plate 14:- Flame structures, unit BRII-6, Beaverlodge River II section.



with or subsequent to Laurentide glaciation. Its stratigraphic position, lying below massive diamicton units interpreted as being deposited by Laurentide glaciation suggests that the sequence was formed prior to the major phase of glacigenic sedimentation in the area. On this basis these units are identified as belonging to stratigraphic unit B.

Similar sequences of sand, gravel and diamicton have been described by, amongst others, Boulton (1971), Visser (1983, 1984), McCabe (1986), and McCabe *et al.* (1984, 1987). These sequences are considered to be typical of ice contact glaciolacustrine or glaciomarine deposition or the pro-glacial or supra-glacial environment. The sediments exposed on the Beaverlodge River differ in that much of the sorted sediment appears to have been deposited by current flow rather than sediment gravity flow. Three possible environments of deposition are proposed:-

i) The sequence was deposited during glacial advance as sub-aqueous outwash from a stream system discharging at the base of the ice, or

ii) Deposition took place in an ice contact delta, with stream flow from a supra-glacial or ice marginal stream, or

iii) Deposition occurred in a pro-glacial, subaerial, fluvial system.

The first two models require the presence of a lake. Such a lake would have been formed by the damming of regional drainage by advancing ice. The local slope is to the southeast, and ice advancing from the north would not form a dam to drainage. Ice advancing to the east of this location would dam regional drainage, however, and could thus have formed a lake. Ice 200 m thick north and east of the Saddle Hills would probably be sufficient to impound a lake covering the Beaverlodge River II section. Continued advance of ice would result in advance into water in this area and makes model iii above unlikely. Laminated silt and clay seen in unit BRII-6 is strong evidence of lacustrine deposition.

It is hard to distinguish sub-aquatic outwash from sub-aerial deposition and the main factor allowing identification of environment of deposition are the associations with overlying and underlying sediments (Rust and Romanelli 1975, Rust 1977, Henderson 1988). Isolated coarse clasts within sand strata are probably dropstones but are not diagnostic of glaciolacustrine deposition. Although commonly derived from floating glacial ice, dropstones are also found in non-glacial fluvial systems, where seasonal freeze on and transport of coarse clasts may occur in winter (Collinson 1971).

The abundance of debris flow deposits derived from remobilisation of glacigenic diamicton means that a source of such material, topographically higher, must have existed. This source is available in a sub-aqueous outwash environment, with diamicton in supra-glacial positions, as well as remobilisation of diamicton melting out at the grounding line (Boulton 1971; Visser 1983; Powell 1981, 1983, 1984; Kulig 1985). If the deposit is the result of pro-glacial outwash or deltaic deposition, then the ice front must have been in the vicinity in order to provide a source of diamicton. It is possible that a minor retreat would result in the local availability of diamicton originally deposited at the base of the ice as lodgment or basal melt-out till.

The strata in the section dip to the south, with the angle of dip decreasing up-section. In a pro-glacial fluvial environment horizontal bedding is the primary feature (Church and Gilbert 1975). Glaciotectonism probably is not responsible for the dip of strata because the dip of the strata decreases vertically, in contrast to common glaciotectonic deformation styles (Moran *et al.* 1980, Aber 1982). The style of deformation expected from ice advancing from the north would probably produce a northerly dip through thrust faulting. Synsedimentary faulting and folding is common in deltas through rapid loading of sediment (Coleman and Gagliano 1965) and this may be the explanation of the deformation observed in this section. The fabrics obtained from diamictons interpreted as debris flows in this part of the section show a dominant clast orientation parallel to the dip of strata, suggesting that this gradient existed during their deposition, rather than being the result of post-depositional tectonic action. Therefore, deposition of these units in a pro-glacial fluvial environment is considered unlikely

A typical delta would not be formed with meltwater entering a lake at the base of an ice dam. Flow conditions are similar in that expansion of flow takes place, and the bedload is dumped as the stream enters the lake, but the formation of foresets requires a increase in lake depth in front of the point of deposition. A sub-glacial stream would enter the lake at its deepest point and would accumulate sediment by vertical aggradation rather than pro-gradation (Rust and Romanelli 1975, Rust 1977).

The base of the section can be interpreted as showing pro-gradation of the delta away from the ice front resulting in progressively fewer debris flow deposits, and more gravel, indicating a stable lake level. The upper part of the sequence suggests a deepening of the lake. The dip of foresets and amount of gravel decreases, and the sediments are generally finer, suggesting more distal deltaic deposition. The transition to laminated silt and clay at the top of the sequence indicates distal lacustrine deposition (Ashley

1975, Ashley *et al.* 1985). Overall, the sequence indicates a deepening of the lake, and a transition from proximal to distal deltaic deposition, although diamictons deposited by debris flow are found throughout. Overlying units indicate glacial advance and the replacement of deltaic/ glaciolacustrine deposition of sorted sediments by glacigenic diamicton.

The sediments observed here are of limited extent (not seen in sections 200 m away) and the sequence is only 8-12 m thick. Thus the delta was relatively small with lake formation being followed by a minor retreat of the ice front from the vicinity of the section. This may have been induced by rapid ablation through the formation of a calving margin as the pro-glacial lake became established. This would explain the transition from proximal deltaic to lacustrine sediments observed, and would provide a source of diamicton for debris flow.

In summary, it is believed that units BRII-1 to 5 represent ice proximal deltaic deposition during a minor retreat of the ice front. Deposition was rapid and was followed by a more extensive advance.

Stratigraphic Unit B-discussion

The stratigraphic succession of units A and B indicate that Unit B was deposited in association with the Late Wisconsinan Laurentide glaciation. The two sections discussed suggest that the sediments contained within them were deposited during glacial advance. They are both located in the Beaverlodge Valley, where ice may have been advancing from the north into pro-glacial lakes formed by damming of drainage to the east. Other isolated occurrences of Laurentide provenance gravel and sand underlying diamicton may be of similar origin. It is also possible that other examples were the result of sub-glacial fluvial activity during Laurentide glaciation.

CHAPTER 5:-STRATIGRAPHY AND SEDIMENTOLOGY - STRATIGRAPHIC UNIT C

Stratigraphic unit C is widespread throughout the map area. It is identified by its lithology, a mostly unstratified diamicton containing all grain sizes from boulders to clay, and also by its geometry- a tabular sheet with little lateral variability. It is thus distinguished from diamictons associated with stratigraphic units B and D, which are thin and discontinuous. Diamicton is also found as a colluvial deposit, and may be confused with stratigraphic unit C in poor exposure, as the grain size distribution is very similar.

Unit C was observed in many exposures throughout the map area. It will initially be discussed by describing the general properties of the unit, the variability of its sedimentology, and subsequently by examining several sections in detail.

General Properties

The general properties observed were thickness, matrix colour, clast lithology, roundness and sphericity, clast fabric, engineering properties, grain size distribution, and sedimentary structures.

Thickness

Diamictons assigned to this stratigraphic unit were observed in over 130 sections. Many of these exposures were poor and did not allow for an evaluation of the true thickness of the deposit. The quality and distribution of the data does not justify the presentation of an isopach map. The thickest deposits are located along the courses of pre-glacial river valleys, with 20 m or more of diamicton along the Pouce Coupe River (section 10.7.6/ 86.46), on Howard Creek, near Spirit River within the Shaftesbury Channel of

Tokarsky, 1967(section 11.7.9/ 86.30), and within the Wembley Channel at the Beaverlodge River I section. Outside of these areas the thickness generally varies between 0.5 and 10 m. In the Saddle Hills a maximum thickness of 1.5 m of diamicton is found. Other topographic highs show a minimal cover of diamicton. Many sections are exposed in river and stream cuts, but the few artificially created prairie exposures show that the thicknesses observed in low topographic sites are not anomalous. The diamicton generally thickens towards the centres of basins, away from topographic highs. Where extensive exposures are found, the diamicton seems to vary laterally in thickness gradually, with the basic geometry being tabular.

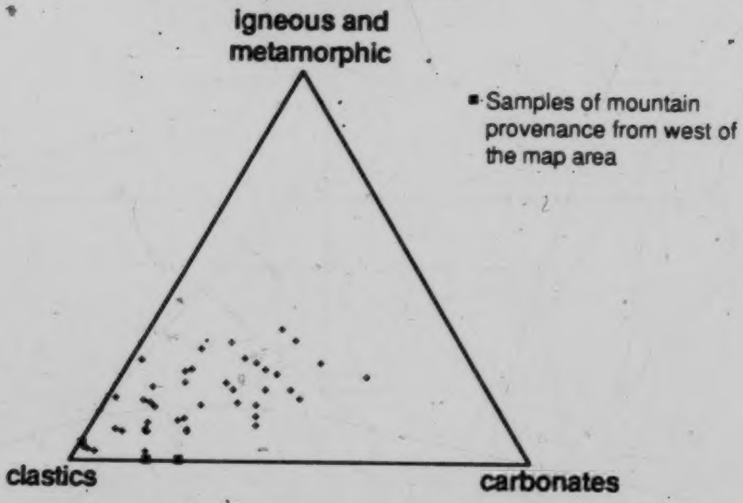
Matrix colour

Observations of matrix colour were made using Munsell colour charts. The results show that there is little variation with the colour of fresh, dry surfaces of majority of samples being light brownish grey (10Y 6/2), greyish brown (2.5Y 5/2), grey (5Y 6/1, 5Y 6/2) or olive grey (5Y 4/2, 5Y 5/2). Colour is of limited use in stratigraphic studies although it has been used as a correlative tool (Stalker 1984). Colour reflects the mineralogy and grain size composition of the matrix. Iron is a major colouring agent, and the state of oxidation is an important control of the resulting colour. Weathered surfaces are distinctly redder, and this indicates that iron (III) oxides have formed through exposure. The minor variations in colour indicate that the matrix mineralogy is much the same over the map area.

Clast lithology

Results of clast lithological studies are presented in Appendix 4 and Figures 24 and 25. Clasts are divided into four groups:-

Figure 24:- Clast lithology of diamictons of stratigraphic unit C



Clastics represents the sum of quartzite and local from the data presented in Appendix 4

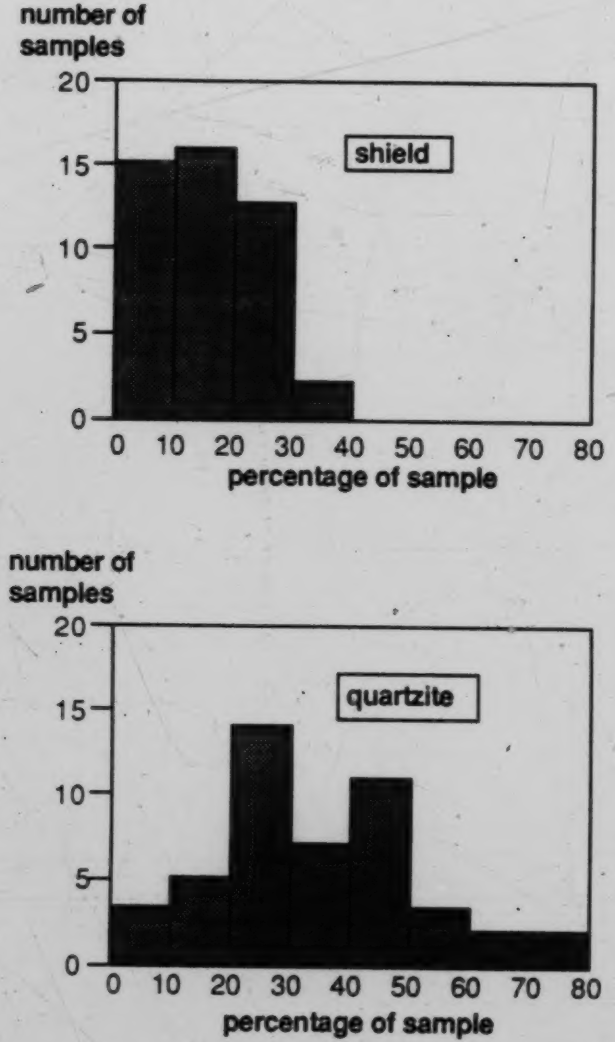


Figure 25:- Clast lithology, diamictons of stratigraphic unit C

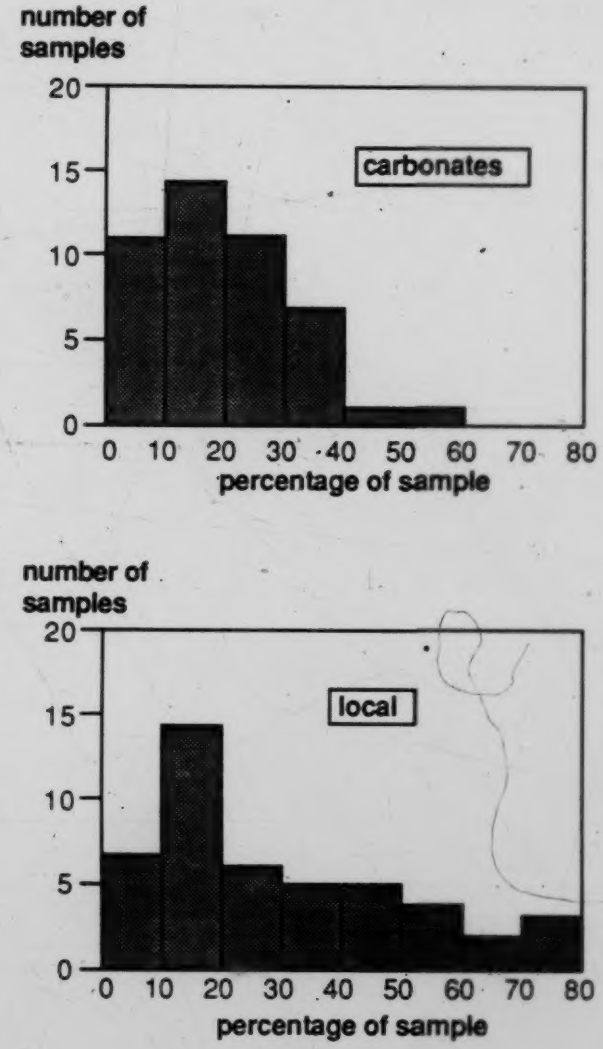


Figure 25 (continued):- Clast lithology, diamictons of stratigraphic unit C

1. *Shield* (igneous and high grade metamorphic rocks); these are mostly pink granitic and pink and grey gneissic rocks, largely derived from the Canadian Shield. Included in this category are grey granitic rocks which may be derived from the Canadian Shield, or from the Cordillera.

2. *Quartzites*:- these are either derived from the Cordillera, where thick sequences of Cambrian orthoquartzite are found or from the Athabasca quartzite on the margins of the Canadian Shield in northeast Alberta. The Athabasca quartzite is pink, with well rounded coarse sand size grains, and little recrystallisation. Cordilleran quartzites can be similar but also are more variable in colour and grain size, and can be completely re-crystallized. It is not always possible to differentiate Cordilleran from Laurentide provenance quartzites with complete certainty, and thus they are grouped together. Also included in this grouping are black and brown cherts, derived from the Cordillera or reworked from local bedrock.

3. *Carbonates*:- this group includes all carbonates, which may be derived from the extensive Palaeozoic sequences of dolomite and limestone exposed throughout the Cordillera, or from the Devonian limestones found at the margin of the Canadian Shield. In the absence of well preserved fossils it is not possible to differentiate between the two sources.

4. *Local*:- this group is composed of clasts of the lithology found only in the local bedrock. These include poorly consolidated claystone, siltstone and sandstone, concretionary ironstone, and coal. Chert pebble conglomerates are also found. These rock types underlie the study area, and are well exposed in the foothills of the Rocky Mountains to the west and southwest.

It is therefore not always possible to clearly differentiate between

Cordilleran and Laurentide provenance clasts on the basis of these groupings. It is also not always possible to recognise material of purely local provenance on the basis of clast lithology, as Cordilleran provenance material was prominent in pre-glacial fluvial systems and may have been reworked into diamictons. The most useful lithology is the pink/ red granitic rocks derived from the Shield. It is readily identifiable in the field, and there is little potential for confusion with other rock types. It is an unequivocal indicator of Laurentide glaciation as the source is located downslope from the study area, and fluvial transport of such clasts can be ruled out.

The slates and low grade schists used in northeast British Columbia by Mathews (1980) to identify Cordilleran provenance material were rarely recognised in samples. This may represent the absence of Cordilleran glacial deposits in the area, although in samples of diamicton of unquestionable mountain provenance sampled to the west of the map sheet such rock types were rare or absent.

40-60 clasts were counted at each location, a number considered too low for strict statistical analysis. To evaluate the usefulness of this data, a comparison may be made with the results of Jones (1961). Jones, working in the southwest of the 83M map sheet identified between 213 and 528 clasts at each of 25 sites. By grouping his results in a similar manner to that used here, they may be compared with those from 12 samples from 8 sites reported in this study, located in the same area of the map (Table 7). The comparison shows that the data obtained for shield and carbonate clasts is comparable, with similar distributions, whereas the data for quartzite and local clasts differs considerably. In the case of quartzite clasts, the mean of the data of Jones (1961) is greater than the maximum observed in this study.

Table 7:- Comparison of clast lithology data from stratigraphic unit C obtained in this study and that of Jones (1961)

This table lists diamicton clast lithology results of Jones (1961) and those obtained in this study. Jones (1961) examined 25 sites counting an average of 350 pebbles. In this study, 12 samples from 8 sites were obtained, with an average of 45 pebbles counted for each sample. For each lithology grouping, a t test has been performed, with the null hypothesis being that the samples were drawn from the same population and the alternative hypothesis that they were drawn from different populations.

Clast Lithology	Origin	Mean	Standard Deviation	Max	Min	t statistic	significance
shield	Jones	21.72	6.66	41.5	10.5		
	this study	18.01	8.26	34.3	7.7	-1.467	0.151
quartzite	Jones	59.24	17.02	78.0	25.5		
	this study	25.98	11.22	44.0	6.1	-6.137	0.000
carbonate	Jones	10.65	15.24	50.0	0.0		
	this study	23.12	15.08	53.7	5.8	2.337	0.025
local	Jones	8.72	5.88	18.5	0.5		
	this study	32.87	25.20	72.5	2.4	4.601	0.000
clastics	Jones	67.96	14.38	89.0	38.0		
	this study	58.85	20.40	86.2	24.4	-1.571	0.125

At a 0.01 level of significance, the results of the t test suggest that the null hypothesis be accepted for shield, and carbonate clast groupings, whereas it should be rejected for local and quartzite clasts. When local and quartzite lithology groupings are classed together into a clastic group, the null hypothesis is accepted.

Conversely, the mean of local clasts obtained in this study is greater than the maximum value observed by Jones (1961). A plausible explanation of these differences may lie in the inclusion by Jones (1961) of "hard sandstone" into the quartzite classification. It is possible that this rock type has been classified as part of the local grouping in this study. If this were so, a grouping of local and quartzite groups into a combined "clastics" group should show similar data distributions in both sets of observations. This has been done in Table 7, and a t test performed. The results of this test show that with this grouping the two studies give similar results. This suggests that the proposal above is correct, and that the clasts have been classified differently in the two studies. Overall the results suggest that the smaller counts performed here give very similar results to the larger counts, and hence have some validity.

Figure 24 combines quartzites and local lithology groupings into a clastic group for the purpose of plotting on a ternary diagram. This is not strictly an accurate classification as these groups incorporate non-clastic sediments such as chert, coal, and ironstone, but is useful for interpretive purposes. This plot shows no distinctive groupings of samples, with most samples dominated by clastics.

To investigate geographical variation in clast composition, a series of contour plots have been prepared using the MacGRIDZO contouring package for the Macintosh computer. This program divides the mapped area into a grid of cells of equal area (in this case 20 by 20 kilometre squares) and computes a value for each cell. This value is based on weighted moments calculated on the nearest 6 data points. The contours resulting thus represent a smoothed surface, rather than a precise rendering of the exact data. Given the variation seen in samples taken from one location (combined into one sample for the purposes of these plots) the relatively low numbers of clasts counted, and the data point density, this is appropriate for recognising broad trends in the data. The location of samples used in this analysis is given in Figure 26.

The degree of smoothing can be evaluated by comparing the raw data for shield clasts (Figure 27) with the contoured plot (Figure 28). These plots must be interpreted with caution, as with the density of data points, and low counts, a single point might have a major effect on the resulting plots. The data is constrained to sum to 100, and thus a major change in any one grouping will affect the other groups.

Given these problems, examination of the plots for Shield, quartzite, carbonate, local, and clastic groupings reveals some broad trends (Figures 28, 29, 30, 31 and 32). Figure 28, which plots percentage Shield clasts, shows a decline in shield clasts towards the west. Three sections outside the map area (86.11, 86.43, and 86.45) were sampled in order to provide samples of diamicton of Cordilleran provenance, and correspondingly show little or no shield material. These data points thus cause a dip in the contours to the west. However, this trend is also observed in the southwest of the map area and is supported by examination of the un-contoured data in Figure 27. The contoured plots of Jones (1961) show a similar trend over his much smaller sample area. This trend may represent :-

i. A zone of a fluctuating boundary between montane and Laurentide ice, as suggested by Mathews (1980), or

ii. Dilution of Laurentide provenance clasts by locally derived material

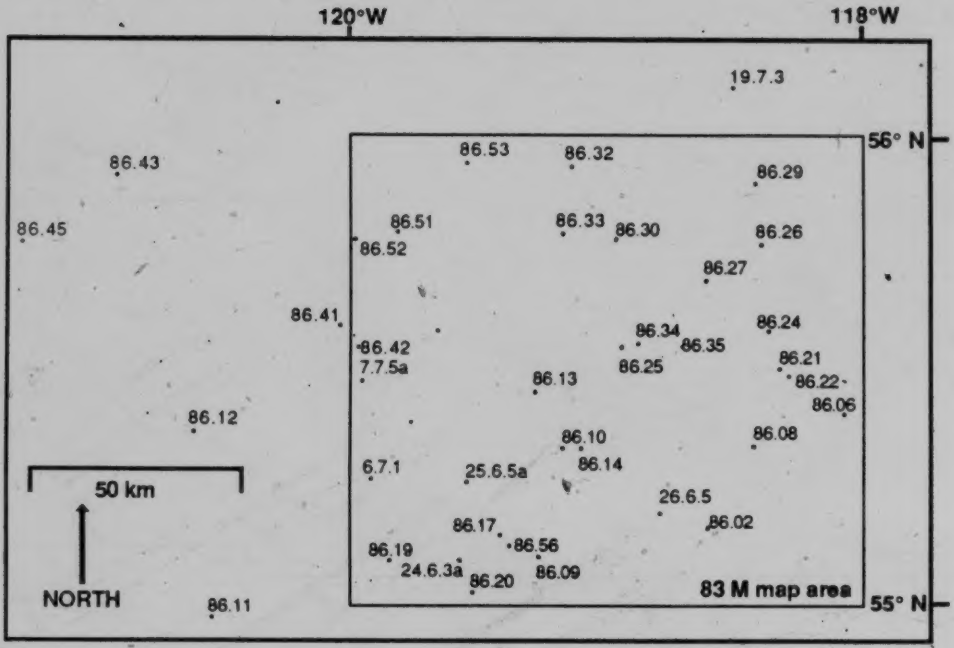

120°W
118°W
56° N
55° N
19.7.3
86.43
86.45
86.53
86.32
86.29
86.51
86.52
86.33
86.30
86.26
86.27
86.41
86.42
7.7.5a
86.34
86.35
86.24
86.25
86.21
86.22
86.13
86.06
86.12
86.10
86.14
86.08
50 km
6.7.1
25.6.5a
26.6.5
86.17
86.02
86.56
86.19
24.6.3a
86.20
86.09
NORTH
86.11
83 M map area

Figure 26:- Locations of sections used in preparing contour maps of pebble lithology

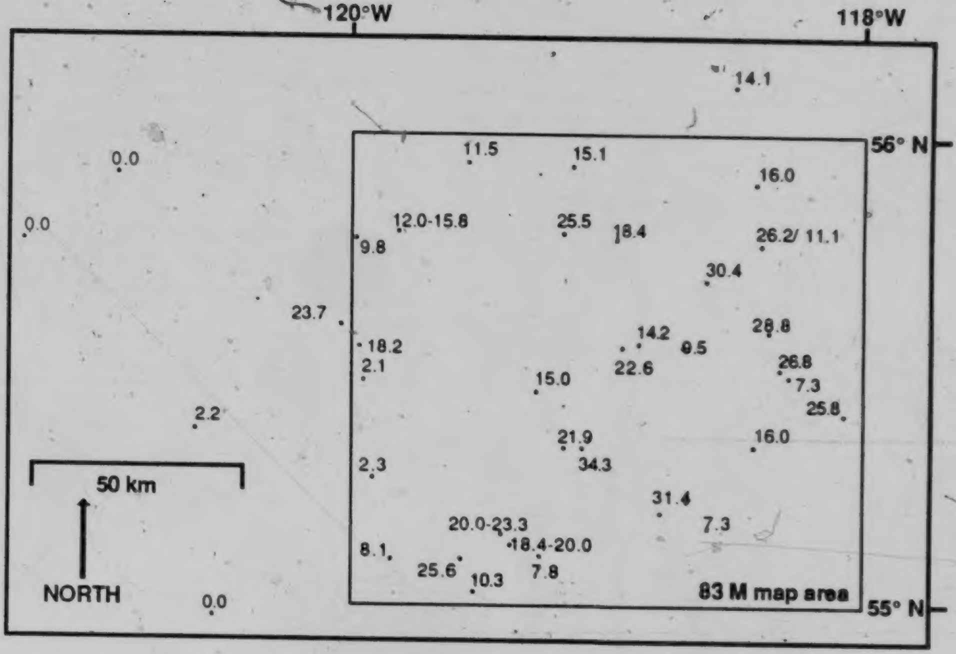

120°W
118°W
56° N
55° N
14.1
0.0
11.5
15.1
16.0
0.0
12.0-15.8
25.5
18.4
26.2/ 11.1
9.8
30.4
23.7
28.8
14.2
9.5
18.2
22.6
26.8
2.1
15.0
7.3
25.8
2.2
21.9
16.0
34.3
2.3
50 km
31.4
7.3
20.0-23.3
18.4-20.0
8.1
25.6
10.3
7.8
NORTH
0.0
83 M map area

Figure 27:- Data used in preparing contour maps of % shield clasts in diamictons of stratigraphic unit C

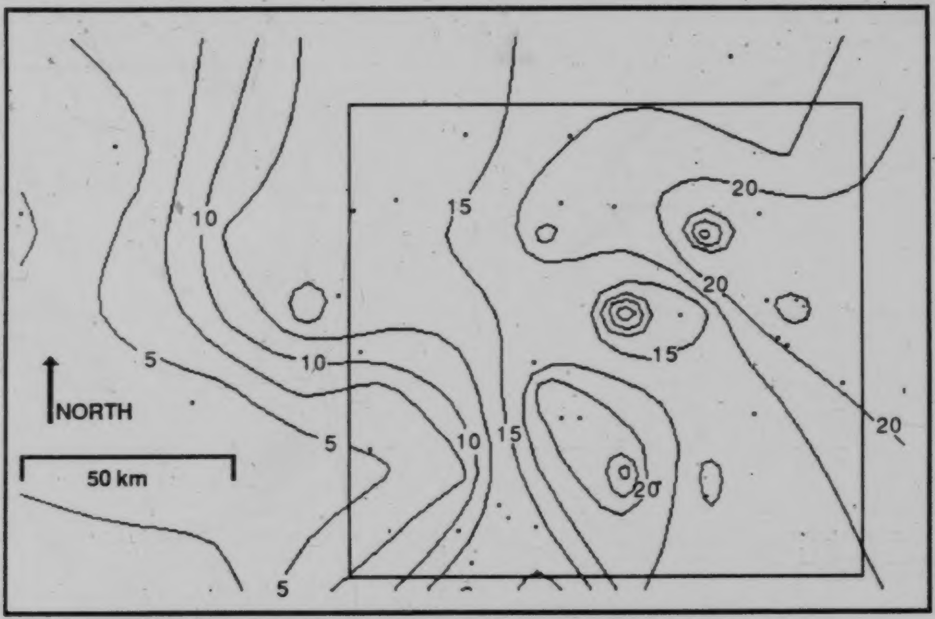

10
15
20
20
15
20
20
5
10
NORTH
5
10
15
50 km
5

Figure 28:- Contour plot of percentage shield clasts in diamicton

Contour interval is 2.5%. Dots represent section locations. See Figure 26 for section numbers; and Figure 27 and Appendix 4 for data. Rectangle represents 83M map area.

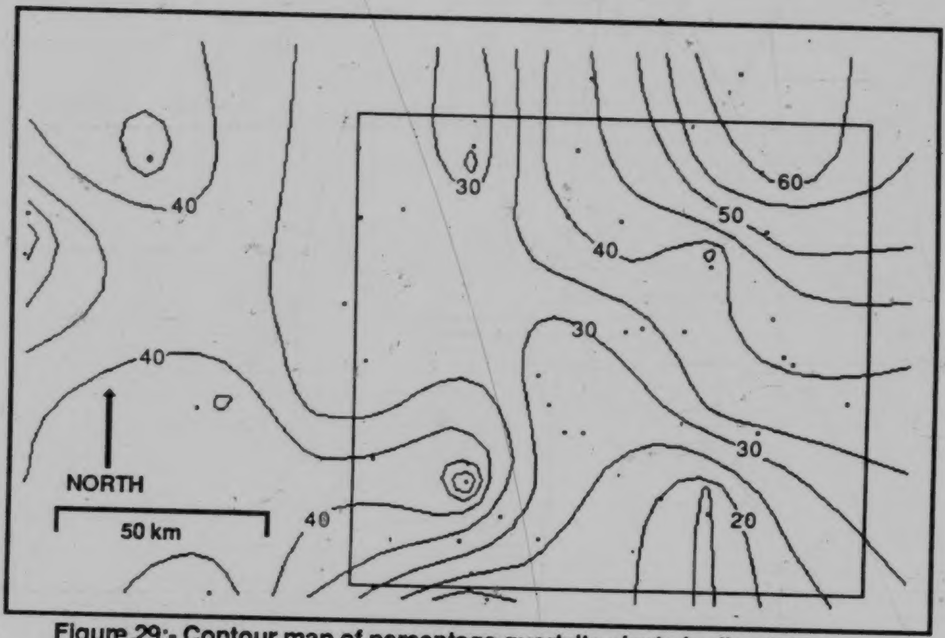

40
40
40
30
40
50
60
30
30
20
NORTH
50 km

Figure 29:- Contour map of percentage quartzite clasts in diamicton

Contour interval is 5%. See Figure 26 and appendix 4 for section locations and data

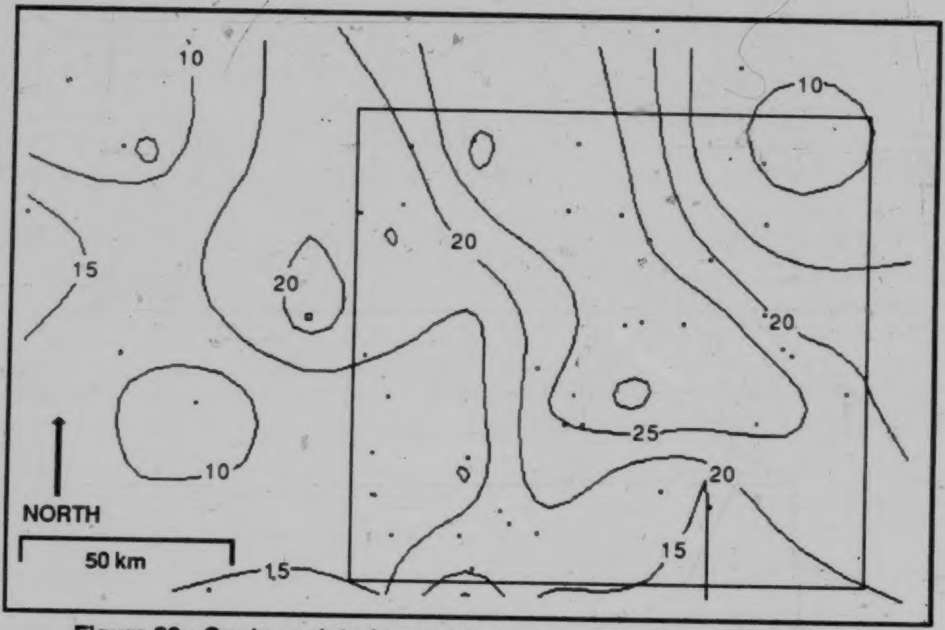
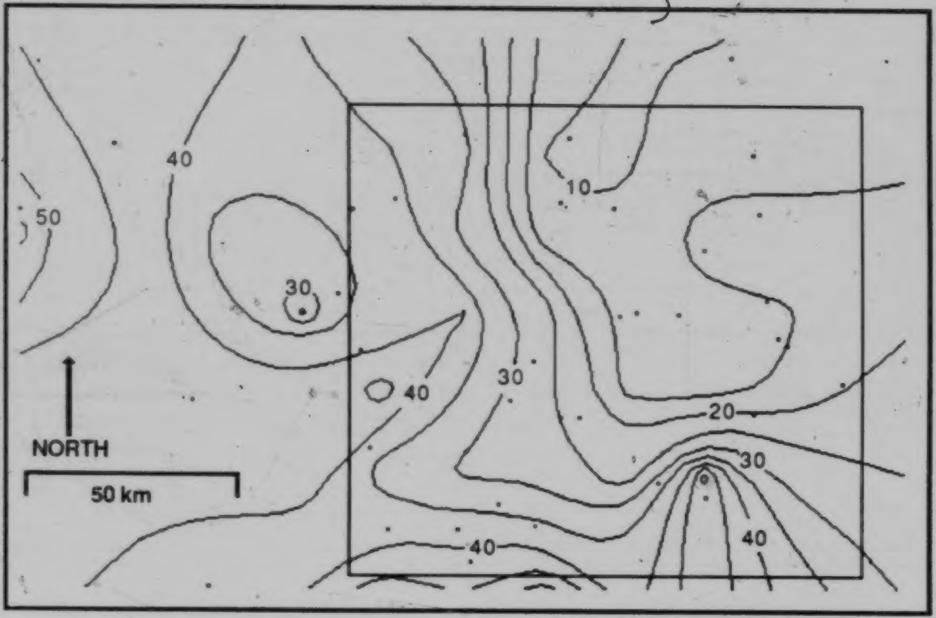

10
10
15
20
20
20
20
25
10
20
15
15
NORTH
50 km

Figure 30:- Contour plot of percentage carbonate clasts in diamicton

Contour interval is 5%. See Figure 26 and appendix 4 for section locations and data



40
50
30
40
30
10
20
30
40
40
NORTH
50 km

Figure 31:- Contour map of percentage local clasts in diamicton

Contour interval is 5%. See Figure 26 and Appendix 4 for section locations and data.

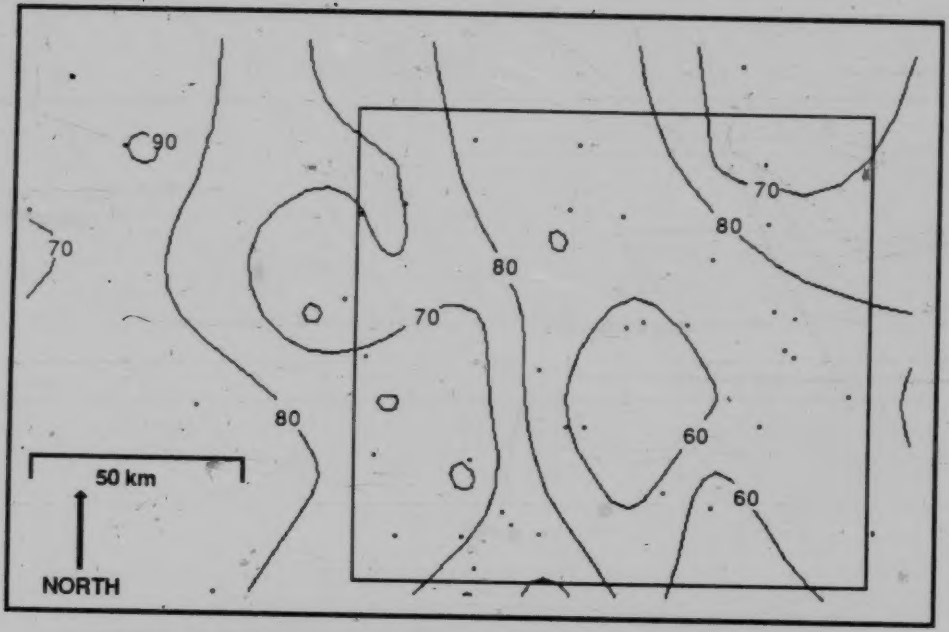

90
70
80
70
80
70
80
60
70
60
50 km
NORTH

Figure 32:- Contour plot of percentage clastic clasts in diamictons.

Contour interval is 10%. See Figure 26 and Appendix 4 for section locations and data

towards the margin of Laurentide ice, or

iii. Reworking of Laurentide provenance material by montane ice, resulting in a dilution by montane provenance clasts.

Contours of percentage quartzite (Figure 29) show a high to the northeast of the map area, a broad northwest to southeast low across the middle of the map, and a broad high to the west. The variation is not great, but a plausible explanation for the pattern is that the high in the northeast is due to the reworking of quartzites from the Shaftesbury and Bezanson preglacial fluvial channels, superimposed on a decline from northeast to southwest of the proportion of Athabasca quartzite, similar to the trend described above for shield clasts. The trends observed here are not reflected by the results of Jones (1961), however, and may be due largely to statistical variation in sampling.

The plot of carbonate percentage composition shows little variation (Figure 30), with a broad high running from northwest to southeast across the map area. The strong east to west increase found by Jones (1961) is not apparent in these plots.

Plotting the percentage composition of local clasts (Figure 31) shows a northeast to southwest increase. This clear trend may be explained in a similar manner to the reverse trend observed in shield percentage, with three hypotheses, each of which would result in the pattern observed.

When quartzite and local clasts are combined into a clastic grouping, no clear trends are found (Figure 32). To some extent the trend observed by plotting solely quartzite is repeated here, but is less well defined.

Thus, examination of the clast lithological data does not allow a differentiation between provenances of diamicton. Both Cordilleran and Laurentide ice are thought to have affected the map area, and it might be expected that diamicton deposited by these ice sheets would show a very different clast composition. This is not the case, with the variation observed showing a close to normal distribution around the mean (Table 8). Probably the best indicator of montane provenance is the absence of pink granites and gneisses derived from the Canadian Shield, although, as discussed above, samples with low proportions of this material may have been deposited by mountain ice reworking previously deposited Laurentide diamicton.

Roundness and sphericity

Roundness and sphericity estimates were made on all clasts collected for lithological analysis using the method of Powers (1953) (Table 9, Appendix 6). The shape of clasts may be indicative of transport path through a glacier (Boulton 1978, Dowdeswell 1986). Boulton and Dowdeswell discussed modern alpine glacial systems which were eroding a substrate of one lithology. Applying their work to prairie glaciation is difficult. Resistance to abrasion is dependent on rock type and thus variable amongst the clasts found in diamictons in the Grande Prairie area. Reworking of clasts into the glacial system is also common, and shape characteristics can be largely inherited from transport in another sedimentary system, rather than being indicative of a particular glacial transport path.

The shape characteristics of over 2000 clasts from 47 samples were measured in this study. The results are summarised by examining the mean values, considering all clasts for each sample, and also by examining the

Table 8:- Summary of clast lithology data

Grouping	mean (%)	standard deviation	skewness	kurtosis
Shield	15.3	9.0	0.12	-0.94
quartzite	35.4	16.6	0.47	-0.55
carbonate	19.7	12.9	0.38	-0.59
local	29.1	21.6	0.71	-0.70
clastic	64.6	18.2	-0.13	-0.88

Table 9:- Summary of clast roundness and sphericity data, stratigraphic unit C

This table summarises the data of Appendix 6. For each of 47 samples, the mean value of roundness and sphericity is calculated for all clasts; and for each lithological grouping. Tabluated below are summary statistics for the sample values (i.e. the mean roundness is the mean of the sample means).

Lithology	measurement	mean	standard deviation	minimum	maximum
All	roundness	.548	.035	.484	.644
	sphericity	.488	.030	.428	.567
	sample size	50.9		22	146
shield	roundness	.516	.061	.382	.716
	sphericity	.485	.078	.366	.700
	sample size	7.55		0	28
quartzite	roundness	.621	0.008	.538	.733
	sphericity	.508	.047	.393	.614
	sample size	18.5		3	52
carbonate	roundness	.544	.071	.400	.766
	sphericity	.486	.051	.300	.600
	sample size	10.9		0	30
local	roundness	.494	.058	.360	.666
	sphericity	.469	.046	.383	.567
	sample size	13.9		1	65

8

variation amongst lithological groupings. The same four groups defined above are used (Shield, quartzite, carbonate, and local). The number of clasts measured for a given lithology can be small at a single sample site (Table 9). This means that some caution has to be exercised in interpreting the results, and detailed statistical work is not possible.

The plot of roundness against sphericity for all lithology and samples shows a tight clustering of points (Figure 33). The range of the data is not great (Table 9). Comparison with the figures of Boulton (1978) shows that most points would plot in the fields dominated by clasts transported in basal positions, rather than supra-glacial positions. Such a comparison is of limited value, given the subjective nature of the observations, and the very different lithology and geomorphology. Examination of the outliers with high roundness values on the plot shows them to be dominated by quartzite. Similarly, outliers on the low roundness side have low proportions of quartzite. Mean values for quartzite show considerably higher roundness values than other rock types. Plotting mean roundness against percentage quartzite shows an apparent straight line relationship (Figure 34), with a correlation coefficient of 0.68. Thus the differences seen appear to be largely governed by lithology.

This is supported by the plot of roundness and sphericity when broken down by lithology (Figure 35, Table 9). It is clear that:-

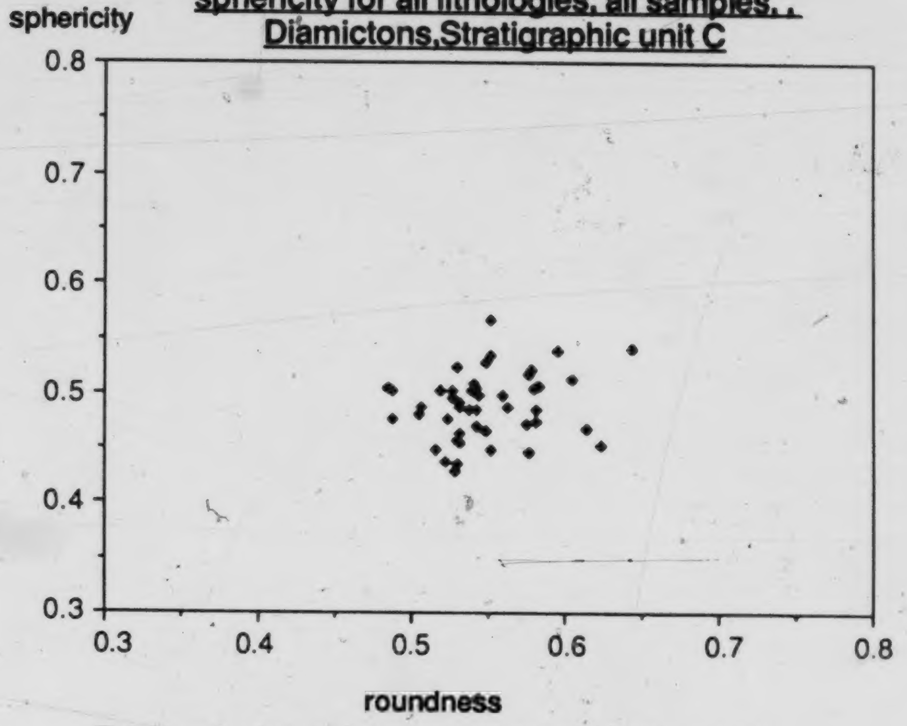
i) sphericity appears to show little variation with lithology;

ii) locally derived clasts show low roundness values;

iii) quartzite shows high roundness values;

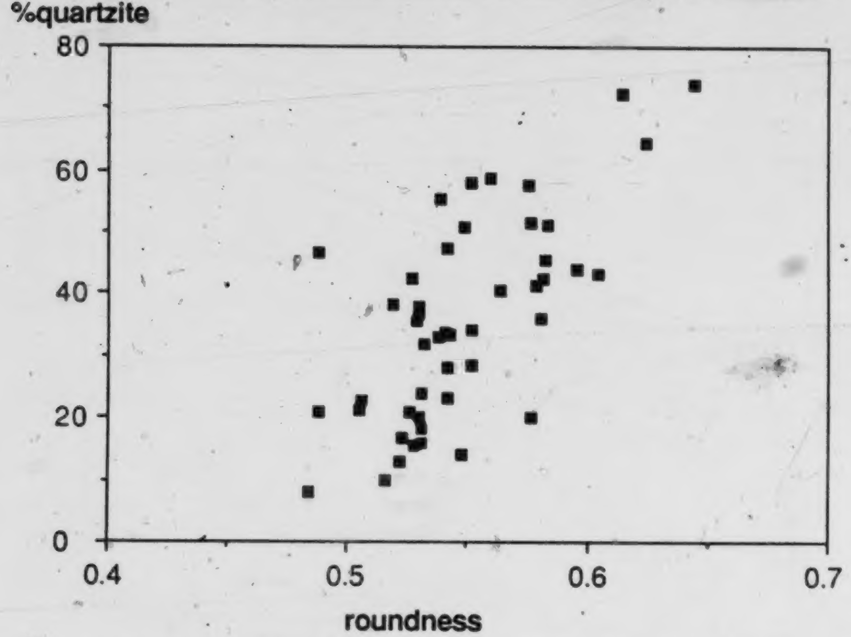
iv) shield clasts are variable in their shape (although this may be the result of

Figure 33:- Plot of roundness against sphericity for all lithologies, all samples, . Diamictons,Stratigraphic unit C



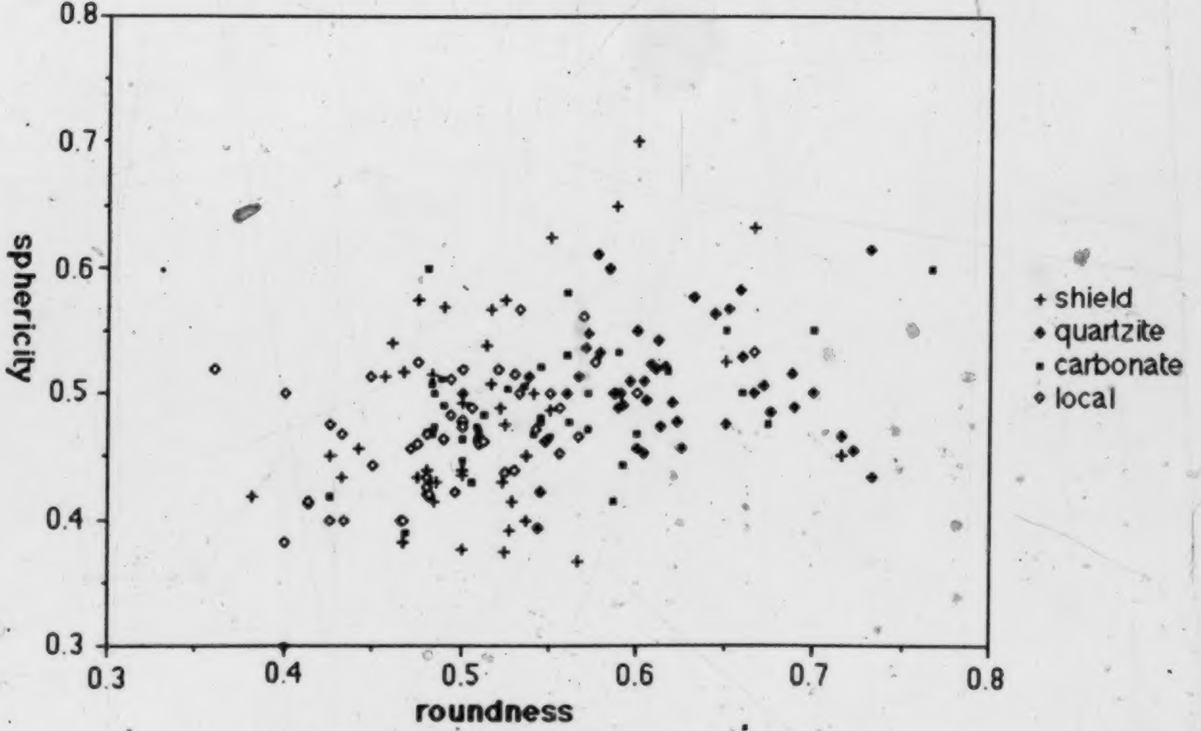
This graph plots roundness against sphericity for all diamicton samples, using the mean values for all clasts measured in a given sample.

Figure 34:- Plot of mean roundness, all rock types, against % quartzite, diamictons, stratigraphic unit C



This figure plots % quartzite for each sample against the mean roundness for all clasts in the sample. It demonstrates a direct relationship with a correlation coefficient of 0.68.

Figure 35:- roundness plotted against lithology for each sample, broken down by lithology



This figure plots the mean roundness against mean sphericity for each sample, with each lithological grouping plotted separately small sample size, with only an average of 7.55 clasts per sample measured).

The high roundness values of the quartzite clasts in the diamicton are probably inherited from fluvial transport, rather than being controlled by glacial transport. Stratigraphic unit A contains abundant well rounded quartzite clasts, and this is probably the source of these clasts in diamicton. The clasts are resistant to abrasion and comminution, and largely retain their original shape.

The angularity of local clasts is due to the lithology of the local bedrock. The clasts measured are largely friable sandstone, and coal, with little resistance to abrasion, and easily broken. It is unlikely that these clasts were reworked and thus their shape reflects glacial transport paths. However, concretionary iron is often found, and these concretions can be well rounded, either by fluvial transport, or in their original form. The single outlier with high roundness consists of measurements on only 3 clasts, and probably has no geological significance. It is likely that the angularity simply represents erosion and transport, with the preservation of such friable clasts indicating that transport was short, and that deposition was not by lodgment.

The shape of Shield clasts is of particular interest, in that stratigraphic evidence presented above suggests that such material must have been deposited by Late Wisconsinan glaciation, and thus has not been reworked from underlying fluvial or glacial deposits. It is conceivable that Shield clasts may have been reworked from fluvial or glacial sediments to the north and east of the field area. However, the sample sizes, and variability of the results means that little meaningful can be said about transport paths.

In conclusion, shape analysis is of very limited use in the Grande Prairie area as a tool for interpretation of transport paths through a glacial system, and environment of deposition of the diamictons. Shape is largely controlled by lithology, and in many cases is inherited from other sedimentary systems.

Clast fabric

Clast fabric is an important indicator of environment of deposition in diamictons. The orientation of clasts is controlled by the processes depositing the diamicton. The significance and interpretation of clast fabric has been reviewed by many authors, including Mark (1973, 1974), Lawson (1979a, 1979b, 1981, 1982), Domack and Lawson (1985), Rappol (1985), Gravenor (1985, 1986), and Dowdeswell and Sharp (1986). In lodgment and basal melt-out till, strong orientations paralleling and transverse to glacial flow direction are expected (Lawson 1979a, 1982, Dowdeswell and Sharp 1986). In basal melt-out till, the fabric may be subsequently modified by reworking. Sub-aerial debris flow results in less well-oriented inconsistent fabrics, sometimes oriented parallel to regional slope (Boulton 1971, Lawson 1979a). Viscous sub-aquatic debris flows result in girdle distributions, generally weakly oriented. Both sub-aquatic and sub-aerial debris flows can raft an internal plug which remains undeformed, and would inherit the characteristics of the original sediment. Fluid sub-aquatic debris flows can form a well oriented fabric (Gravenor 1986). Diamictons deposited as a result of rain-out from floating ice have a variable fabric. Schmoll (1961) reports weakly oriented flat lying fabrics. Domack and Lawson (1985) report high proportions of vertical clasts, and a weak orientation.

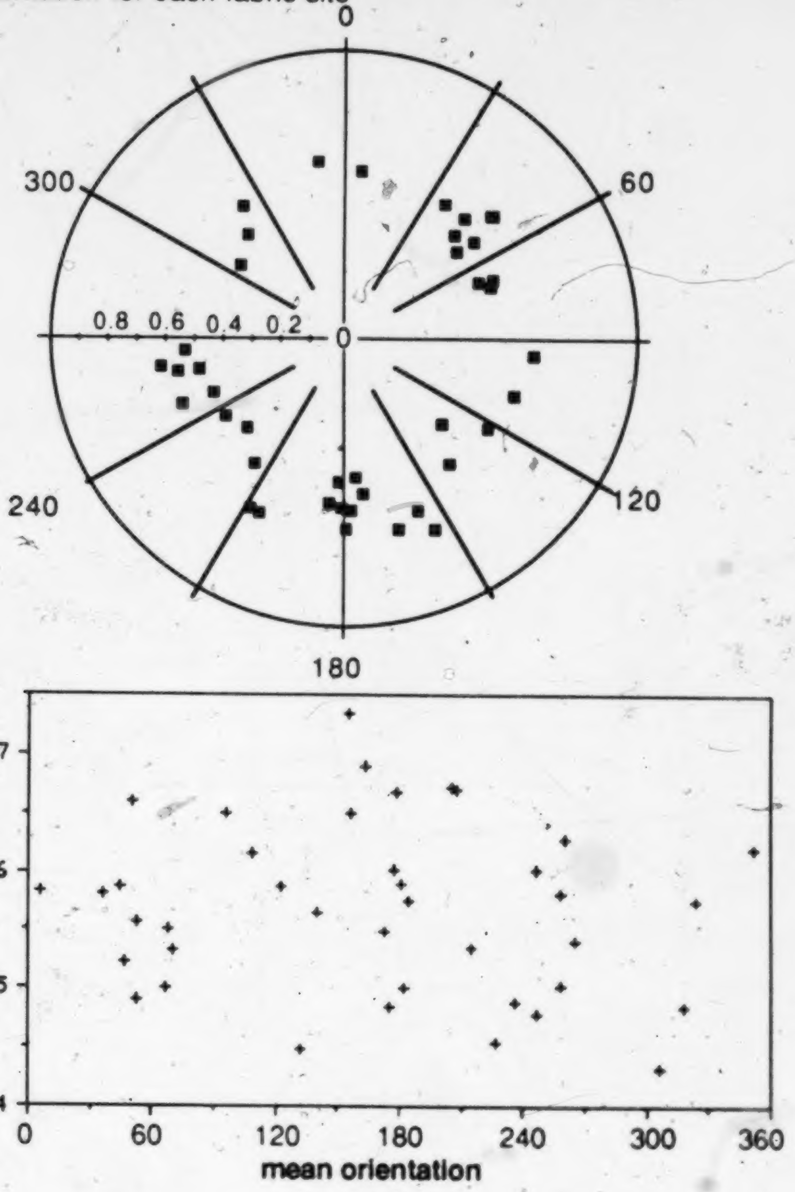
At sections throughout the area 25 stone clast fabrics were obtained from mainly massive diamictons of stratigraphic unit C. In a few cases a series of fabric determinations were made vertically through thick diamicton sequences. Mean orientations, and strength of alignment was calculated by the eigenvector methods of Mark (1973, 1974) and Woodcock (1977). The normalized eigenvalues (the eigenvalue divided by the sample size) gives three measures of strength of orientation. The S1 value marks the strength of the primary (mean) orientation. The S2 value is that orientation orthogonal to the S1 orientation that explains the maximum amount of remaining variation. The S3 value is orthogonal to S1 and S2. S3 is thus the pole to the preferred plane through the fabric, and accounts for the remaining variability. S1, S2, and S3 must sum to unity. In a random fabric, the three values will be near equal. Lawson (1979a) suggested that lodgment and basal melt-out till fabrics will have S1 values ranging from 0.7-0.9, whereas debris flows give lower results. High S1 values indicate a cluster distribution, but if S1 is approximately equal to S2, and greater than S3, then a girdle distribution is indicated.

Fabrics obtained from diamictons of stratigraphic unit B in the Beaverlodge River II section and thought to represent debris flows gave S1 values of 0.50 to 0.59. A single fabric was obtained from dropstones in glaciolacustrine silts and clays from the Beaverlodge River III section, and gave an S1 value of 0.54.

The results are listed in Appendix 2. A number of plots are used to present results, including a plot of S1 against azimuth of mean orientation (Figure 36), a map of variation in S1 and azimuth over the study area (Figure 37), a ternary plot of S1/S2/S3 (Figure 38), and a logarithmic plot of ratios of S1 to S2 and S2 to S3 (Figure 39) (c.f. Woodcock 1977, Lawson 1979a,

Figure 36:-Plot of primary mode of fabrics, and strength measured by S1 value,diamictons, stratigraphic unit C

Each diagram presents the same data, and plots S1 against mean orientation for each fabric site



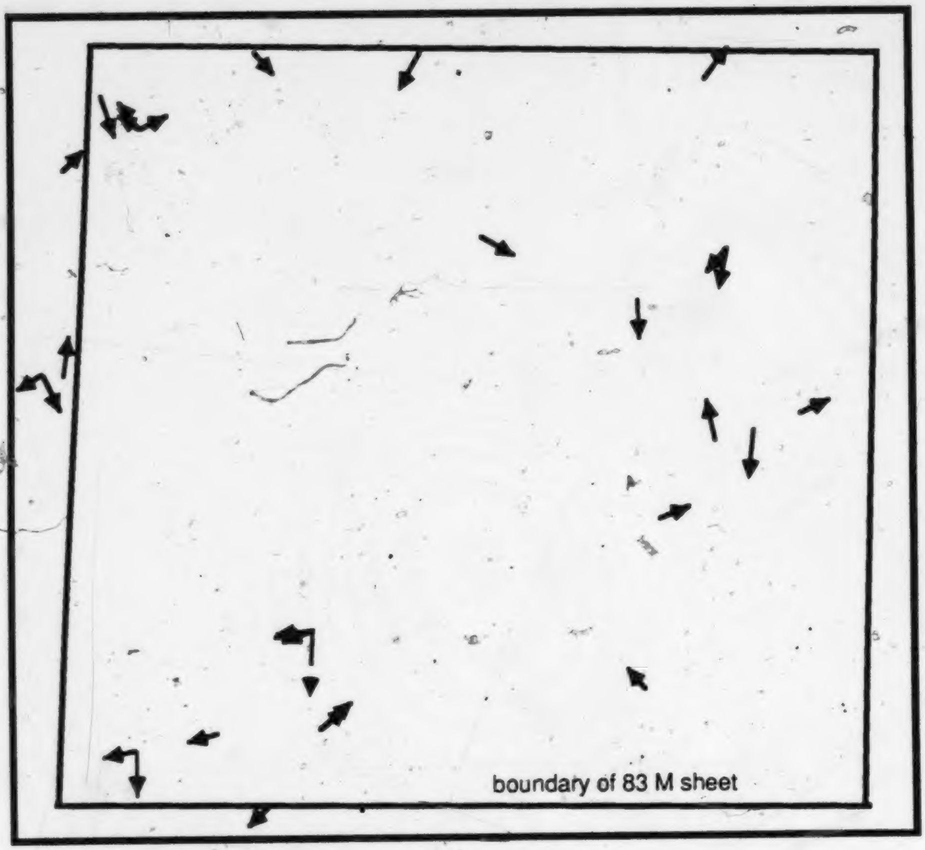

boundary of 83 M sheet

Figure 37:- Mean orientations of clast fabrics, 83 M map area

This map plots direction of S1 values, with the length of arrow proportional to the strength of orientation

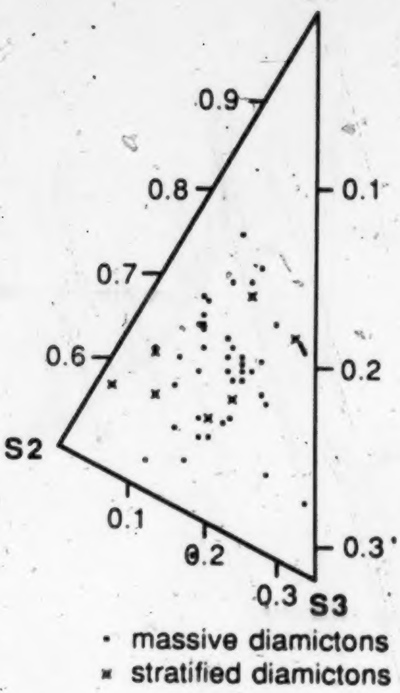
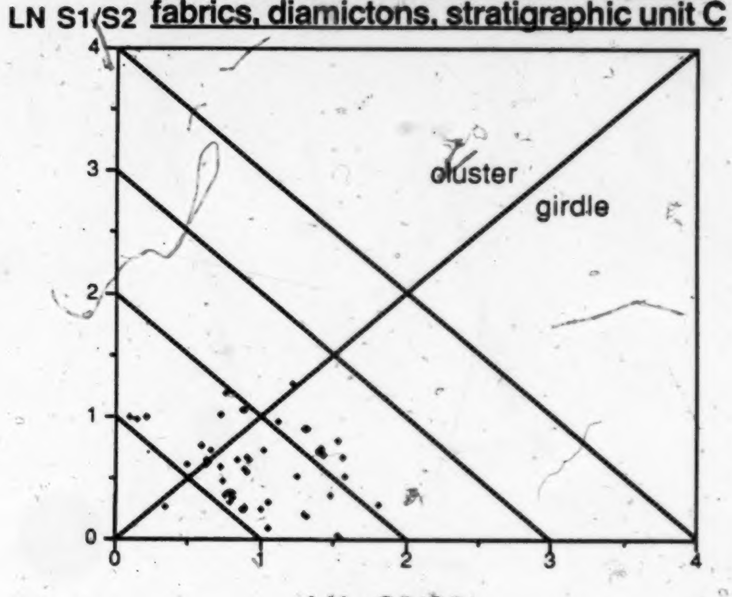


Figure 38:- Triangular plot of normalised eigenvalues

After Lawson 1979a

Figure 39:- eigenvalue ratio plot for clast fabrics, diamictons, stratigraphic unit C



LN S2/S3

This plot is of the natural logarithm of the ratio of normalised eigenvalues after Woodcock (1977) and Rappol (1985). The parallel lines mark increasing values of the strength parameter towards the top right of the diagram, whereas the distribution type is separated by the line dividing girdle distributions from discrete clusters

Rappol 1985).

Examination of these plots shows, firstly, that there is no dominant regional orientation of fabrics. Figure 36 shows that the mean orientations plotted are very variable, but clusters may be noted at due south, with 7 samples closely aligned, and also a broad northeast/ southwest trend. Neither of these trends are clearly defined. Figure 37 suggests there is no consistent areal pattern.

Secondly, the S1 values are low. The highest is 0.74, but the majority lie between 0.4 and 0.7. S3 values are correspondingly high, and this indicates that the fabrics in general are weak. The eigenvalue ratio plot (Figure 39) shows the majority of fabrics to show girdle distributions, and all of moderate to low strength. Comparison with the equivalent plot of Rappol (1985) shows that the fabrics from stratigraphic unit C are generally weaker than those from the diamictons studied by Rappol, but show similarities with the fabrics obtained from debris flows.

The ternary plot of S1,S2, and S3 (Figure 38) allows comparison with the results of Lawson (1979a, 1982) and Dowdeswell and Sharp (1986). Only one fabric from this study plots in the basal melt-out till field or lodgment till field as defined by these authors. The debris flow field contains many of the fabrics measured in the Grande Prairie region. However, this plot should be used with caution, as other authors have found less well oriented fabrics in basal tills, and better oriented fabrics in debris flows (Mark 1974, Mills 1977, 1984, Rappol 1985, Dowdeswell and Sharp 1986).

The weak fabrics found regionally might be related to clast lithology. As discussed above, much of the clasts measured are well rounded quartzites of moderate sphericity. It is likely that fabric measurements on such clasts will be less precise than on elongate angular clasts, due to the difficulty of identifying the orientation of the long axes. However, an effort was made in the field to only measure clasts with a clear long axis orientation, and it is unlikely that this is the major cause of weak fabrics.

Although fabrics cannot uniquely identify an environment of deposition, those found in the Grande Prairie region indicate that there are few or no examples of lodgment or undisturbed melt-out till in the area. If such sediments were found it would be expected that fabrics would be stronger, and show a consistent mean orientation (Shaw 1982, Dowdeswell and Sharp 1986).

Engineering properties

Atterberg limit determinations were made only at two sections, on three samples. Results show liquid limits of 27.0, 34.0 and 44.1, and plastic limits of 12.0, 19.6, and 18.4 (Figure 10). These results are consistent given the limitations of the laboratory work, and show that the diamictons probably contain both montmorrillonite and illite in the clay fraction, and should be considered low plastic sandy and silty clays (Holtz and Kovacs 1981).

Grain size distribution

Grain size analysis was performed on over 50 diamicton samples of stratigraphic unit C. The results are summarised in Figures 40 and 41, and in Appendix 3. As discussed above, the use of conventional grain size parameters (Folk and Ward 1957) is avoided as the high clay content would require considerable extrapolation in order to estimate the extremes of the distribution. Thus the most useful summary statistic is that of sand/ silt/ clay proportions. The mean values are 17.5% sand, 34.7% silt and 40.4% clay.

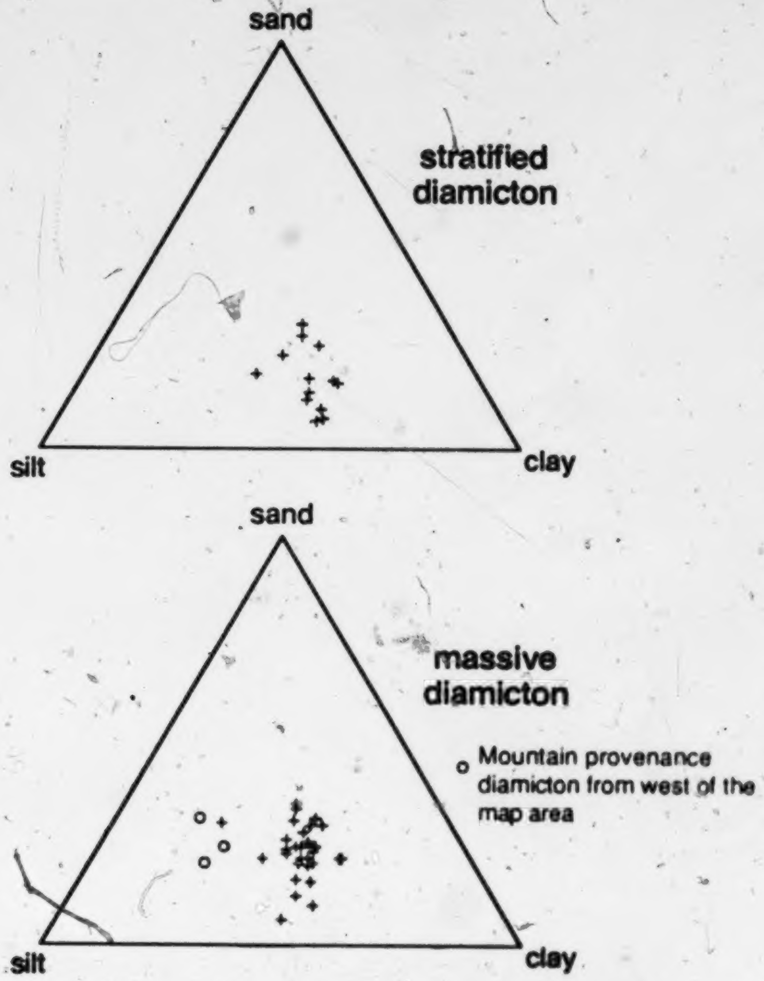


Figure 40:- Ternary diagrams, texture of diamicton (Stratigraphic unit C)

The diagrams plot the result of grain size analysis on diamictons of stratigraphic unit C. They are separated by sedimentary structures, with any diamictons apppearing banded, or containing sorted strata plotted in the upper diagram, and massive diamictons in the lower.

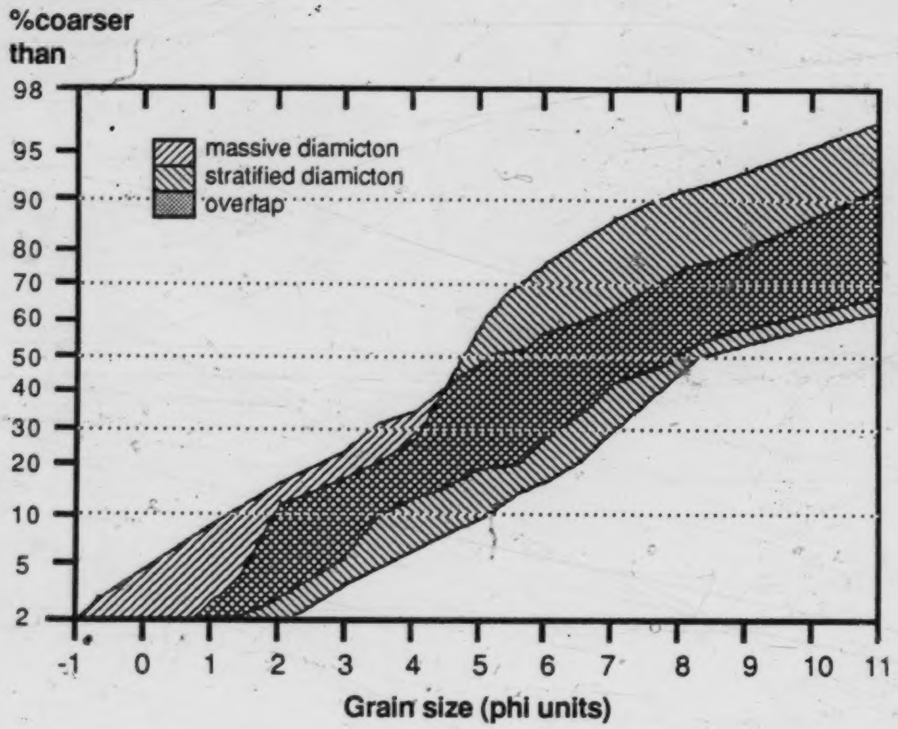


Figure 41 :- Grain size envelope, stratigraphic unit C

All grain size curves from samples of this stratigraphic unit plot within the envelope shown. Diamictons are separated by presence or absence of stratification

Textural results from any diamictons showing any evidence of sorting in the form of discrete laminae or a large scale banding are plotted on a separate diagram from those appearing unstratified (Figure 40). The two classes plot in a broadly similar area, with a slight trend for the stratified diamictons to contain slightly less sand. Both plots show a consistent composition for the diamictons, with a few outliers. Unstratified diamicton samples show a poorly defined second grouping with less clay than other samples.

Little can be said about the genesis of these sediments from grain size analysis alone. The poor sorting suggests that flowing water was not involved to any great extent in their formation, and is typical of diamictons deposited by glacial activity.

Grain size analysis measures the matrix composition only. The proportion of clasts greater than sand size was estimated visually in the field. Such estimates are very approximate, and only allow a qualitative classification. The majority of diamictons had clast contents estimated at 5 to 10%. Rarely diamictons appeared to be enriched in coarse clasts, with up to 20%, and more commonly lower clast contents of 1 to 5 % were found.

Sedimentary structures

The diamictons observed in section were mostly unstratified, with few obvious sedimentary structures. Detailed examination revealed the following common structures:-

i. Sorted lenses:- Lenses were mainly of sand, and usually deformed, with original morphology modified.

ii. Laminae:- laminae of sand, silt, and clay composition were observed. Laminae of sand were rare. Clay and silt laminae were commonly found in diamictons throughout the area. They were often concentrated at the top or base of the diamicton unit.

iii. Banding:- In some sections a vague colour banding could be observed in otherwise unstratified diamicton, with a scale of 0.5 to 2 m.

iv. Intraclasts:- intraclasts of clay and silt were rarely observed , mainly towards the top of massive diamicton units

Section descriptions

The general properties of diamictons observed throughout the field area give some information as to how the sediments were deposited. The tabular geometry, erratic clasts of shield provenance, and poorly sorted matrix suggest that the diamicton is of glacial origin. The generally weak inconsistent fabrics suggest that lodgment till is rare to absent, and that undisturbed basal melt-out till is uncommon. Sedimentary structures, particularly the common clay lamination, indicates that standing water was present and important in the deposition of stratigraphic unit C. To enable a more precise evaluation of the environment of deposition of this unit, three well exposed sections will be discussed. The Beaverlodge River II section and the Saddle River section show more than a single diamicton unit. The Henderson Creek section displays thick well exposed cuts through a single diamicton unit.

Beaverlodge River II section

This base of this section (units BRII-1 to 6) has been described above (Figure 19). The remainder of the section will be discussed here, with, initially, a more detailed interpretation of unit BRII-6 (see Plates 12 and 14).

Interpretation- unit BRII-6

As discussed above the laminated silt and clay component of this unit is suggestive of glaciolacustrine deposition. The underlying units have been interpreted as showing deltaic deposition into a pro-glacial lake, and these finer grained lacustrine deposits indicate a transition from deltaic to lacustrine deposition. The diamicton interbeds are discontinuous, with pronounced "noses" and are internally stratified. On this basis they are interpreted here as sub-aquatic debris flow sediments. The clay laminae within the diamicton strata would thus be deposited by suspension settling during the intervals between a series of debris flows. The lateral transition from diamicton to graded lamina indicates a transition from plastic to fluidal flow, due to the incorporation of fluid into the flow (Nardin *et al.* 1979). Flame structures in the silt/ clay rhythmites suggest loading by debris flow.

An alternative explanation is that the lacustrine sediments have been incorporated into glacial ice as frozen blocks and then deposited through melt-out. The tight folds would be explained by deformation during transport, but overall the lake sediments are relatively undeformed. Folding has been observed at the base of debris flows and interpreted as the result of drag folding by the movement of the debris flow (Evenson *et al.* 1977, Kulig 1985).

Unit BRII-7:- diamicton

Unit BRII-7 is 2.5 m thick, and continuous over the entire exposure (Plate 12). It consists of a massive light olive grey (5Y 6/2 dry, fresh) recessive diamicton. In the basal 0.5 m discontinuous laminae and wisps of clay were observed. Clasts up to 35 cm diameter are found, and clast lithology is varied, with locally derived sandstone dominant, quartzite, granite, and limestone common, with coal and concretionary iron present (Figure 20).

Modal sphericity is 0.5 and modal roundness is 0.6 (Figure 23)

Two fabrics were obtained from unit BRII-7 (Figure 22), the first from 0.5 m above the basal contact, and the second from 0.5 m below the upper contact. The lower sample shows a weak girdle distribution (S1=0.47), with a modal azimuth of approximately 250. The upper sample shows a moderate bimodal distribution (S1= 0.54, S2= 0.37) with modes at 265 and 356 azimuth.

Interpretation

The presence of Laurentide clasts, the tabular geometry and the poor sorting indicates that this sediment was deposited in association with Laurentide glaciation. The two fabrics obtained from unit BRII-7 are consistent in their mean orientation, but have low S1 values (0.47 and 0.54). They show generally low dips. Lodgment and melt-out tills show a strong orientation with S1 values in the order of 0.7-0.9 (Lawson 1979a, Dowdeswell and Sharp 1986). However, the eigenvalue method is designed for evaluating unimodal distributions (Mark 1973), and both these fabrics are bimodal. In both cases the second mode is at approximately 90° to the primary mode, and is measured by the S2 value (Figure 22). Thus the S3 value represents the variability that cannot be accounted for by a transverse/ longitudinal arrangement of clasts, and in both cases S3 is comparatively low (0.15 and 0.08). Such fabrics are compatible with an origin as lodgment, basal melt-out, or debris flow deposition. The consistency of orientation between the two fabrics suggests that supraglacial melt-out is unlikely (Boulton 1971). The absence of high dips and the relatively strong orientation mitigates against rain out (c.f. Schmoll 1961, Domack and Lawson 1985). Debris flow cannot be ruled out on the basis of consistency of orientation as this would be found if the local slope remained the same throughout deposition.

The clast lithology and roundness data suggests that neither supra-glacial melt-out nor lodgment was the mode of deposition. Supra-glacial melt-out till is generally thought to contain a higher proportion of angular and non-local clasts than basal melt-out or lodgment till (Boulton 1978). Lodgment till contains a high proportion of faceted, striated clasts (Boulton 1972, 1978). The presence of well rounded clasts, and the absence of faceted, striated clasts suggests that Unit BRII-7 was not deposited by supraglacial melt-out or lodgment processes.

The texture of the unit does not provide much information, but the grain size distribution is similar to unit BRII-1 and diamicton in unit BRII-6, both of which are interpreted as resulting from sub-aquatic debris flow.

The presence of clay laminae within the otherwise unstratified diamicton is an important line of evidence. The fine grain size of the laminae suggests that they were deposited by suspension settling in standing water. This, combined with the association with lacustrine sediments and debris flow deposits of the underlying unit BRII-6, suggests that unit BRII-7 may be composed of a series of sub-aquatic debris flows, with clay deposition in the intervals between flows. Basal melt-out into a sub-glacial body of standing water might result in a similar sequence but the association with underlying units suggestive of the presence of a pro-glacial lake favours the former hypothesis.

Thus, although definitive evidence is lacking, it is suggested that unit BRII-7 was deposited largely by sub-aquatic debris flow at an ice margin, in a similar manner to that proposed by Evenson *et al.* (1977), Visser (1983), and Kulig (1985). The source of sediment for the flows was probably basal melt-out till, deposited at the grounding line of the ice margin.

Unit BRII-8, diamicton

Unit BRII-8 consists of 3 m of light brown diamicton (10YR 6/3, dry fresh). It is more resistant than the underlying diamicton, and has columnar joints (Plate 12). It is mainly unstratified, but contains a single 1 m long biconvex sand lens close to the basal, gradational, contact.

A single fabric 1.5 m above the contact shows a moderately oriented bimodal fabric (S1= 0.63, S2= 0.30) with modes at 265 and 340 azimuth (Figure 22). Clast lithology is varied, with common quartzite, sandstone and granite, and lesser proportions of concretionary iron, gneiss, and limestone. Modal roundness is 0.6, and modal sphericity between 0.4 and 0.5 (Figures 20 and 23).

Interpretation

Unit BRII-8 shows many similarities to unit BRII-7, especially in the clast composition, roundness, and sphericity (Figures 20 and 23). It differs in its grain size distribution, containing significantly more sand, and shows a stronger fabric. The alignment of the primary mode is almost identical to that of the upper fabric of unit BRII-7 (11/ 265 as opposed to 11/ 246). Unit BRII-8, however, lacks the clay laminae observed in unit BRII-7, generally shows a stronger clast orientation, and contains a single biconvex lens. A biconvex shape suggests englacial formation, with erosion of underlying and overlying ice by water (Rothlisberger 1972, Haldorsen and Shaw 1982). Lenses associated with debris flows are plano-convex (Kulig 1985, Levson and Rutter 1986). An undisturbed, biconvex lens strongly supports a basal melt-out origin for the diamicton.

The features characteristic of lodgment tills such as fissility, bullet-shaped clasts, strong fabric, or a high proportion of local material (Dreimanis 1976, Boulton 1975, 1978, Müller 1983, Dowdeswell and Sharp 1986) are absent. Thus basal melt-out is considered to be the likely origin of this unit.

The contact between units BRII-7 and BRII-8 is gradational, suggesting a gradual transition between debris flow and basal melt-out. Both processes probably operated simultaneously, and it is possible that during the final stages of the deposition of unit BRII-8, as ice retreated, debris flow became the dominant process. It is difficult to separate the two methods of sedimentation unless there is good exposure, as debris flows probably resulted from remobilisation of diamicton deposited as basal melt-out till, and would inherit much of their character.

Unit BRII-9:- laminated silt and clay

Unit BRII-9 overlies unit BRII-8 along a sharp horizontal contact, and is 0.70 m thick. It consists of rhythmically laminated silt and clay, with each rhythmite consisting of a normally graded silt to clay lamina. Clasts which deform underlying laminae and are draped by overlying laminae are common at the base but decline in number upwards. Laminae are 0.1 to 0.2 cm thick at the base of the unit, thin over the basal 20 cm, and then thicken to 0.8 to 1.0 cm at the top of the unit. The upper part of the unit has been altered by pedogenesis.

Interpretation

Unit BRII-9 may be considered to be representative of stratigraphic unit D, and thus will not be discussed in detail here. The abrupt contact between units BRII-8 and BRII-9 suggests that retreat was comparatively rapid following the establishment of a pro-glacial lake. There is no evidence of ice proximal post-glacial lacustrine sedimentation in this section although such sediments were observed in the Beaverlodge River III section close by.

Summary-upper units, Beaverlodge River II section

Although interpretations of the origins of the diamicton units are tentative, this section is thought to show a transition from deltaic/ lacustrine deposition of mainly sorted sediments to lacustrine ice-marginal debris flow sedimentation to basal melt-out till. Although there are two distinct diamicton units in the section, sedimentological evidence strongly suggests that they were deposited during a single glacial advance.

Saddle River section

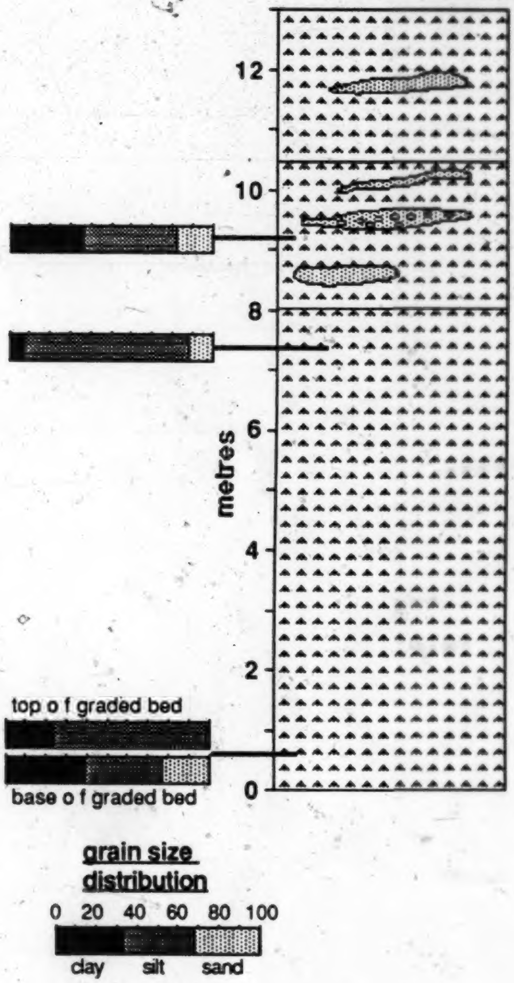
This section is located in the valley of the Saddle River, south of the Peace River (Appendix 1). Three distinct diamicton units totalling over 12 m in thickness are exposed (Plate 15). It has been briefly discussed in Bobrowsky *et al.* (1987).There is abundant evidence of colluvial activity in the area in the form of rotational slumps and other slope failure, and there is considerable doubt as to whether the section is undisturbed. As it is one of only a few sections in the area that clearly shows more than one diamicton unit, it is discussed below.

Unit SA-1-Description

Unit SA-1 consists of 7 m of stratified diamicton, which overlies bedrock (Figure 42). The unit is prominent with little columnar structure. From a distance eight to 10 distinct strata 10-15 cm thick divide the unit into discrete beds of diamicton (Plate 15). These strata consist of laminated silt and clay, with few clasts. Laminae are discontinuous and contorted. The strata generally lie horizontally but.dip to the west at the east end of the section.

Plate 15:- Overview, Saddle River section. Linda Halsey for scale.

Figure 42:- Stratigraphic column, Saddle River section


12
10
8
6
4
2
0
metres
top o f graded bed
base o f graded bed
grain size distribution
0 20 40 60 80 100
clay
silt
sand

Unit SA-3:- gradational basal contact into resistant diamicton with rare sand/ silt lenses

Unit SA-2:- Diamicton with many sand, gravel, and silt lenses and stringers. Basal contact is sharp

Unit SA-1:- diamicton, consisting of 8-10 normally coarse-tail graded beds, top of each bed contains many discontinuous silt laminae

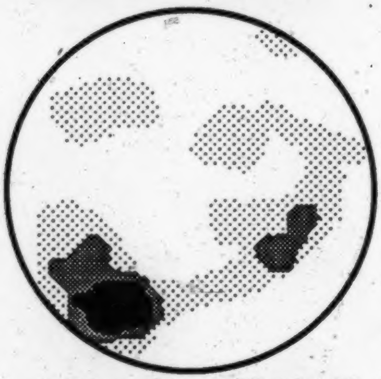
The beds lying between laminated strata consist of diamicton and are 0.5 to 1 m thick. The beds show normal grading of coarse clasts, with a concentration of pebbles at the base of the bed, and few clasts at the top. The overall proportion of clasts is low (2-5%). The matrix of each bed is graded, with 20% sand at the base, and 1% sand at the top (Figure 42), although the proportion of clay changes little. The clast assemblage is dominated by quartzite, with minor limestone, coal, granite, sandstone and gneiss (Figure 44). The high proportion of quartzite is reflected in the clast shape, with most clasts having a roundness between 0.5 and 0.7, and moderate sphericity (Figure 45).

A 25 stone clast fabric from this unit shows a weak southwesterly orientation (S1= 0.57), and a secondary mode to the southeast (Figure 43).

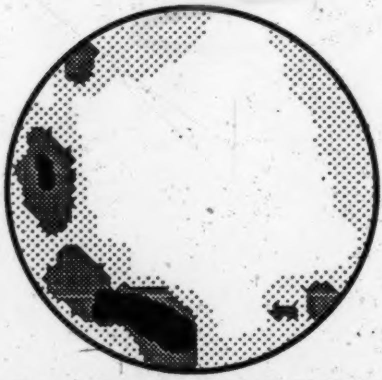
Unit SA-1- Interpretation

The weak fabric and normal grading indicates that unit SA-1 was not deposited as a till, but as a sediment gravity flow. Visser (1983) described stacked beds of diamictite showing vertical grading into argillite, and interpreted these as being deposited by cohesive debris flow. Normal grading in sediment gravity flows results when high water content decreases viscosity and buoyancy, and allows coarse particles to sink to the bottom of the flow. The matrix grading of unit SA-1 suggests that the flow depositing it was less cohesive than that depositing the sediments described by Visser (1983). The poor fabric suggests, however, that the flow was viscous, in contrast to the parallel clast orientations of fluidal flows (Nardin *et al.* 1979). The fabric was obtained from the base of a graded bed, and so it is possible that the sediment represents a transition from viscous debris flow at the base

Figure 43:-Fabric measurements, Saddle River section



unit SA-1, S1= 0.57 39/185, S2= 0.28 23/074, S3= 0.15 42/322



unit SA-2. S1= 0.53 18/215, S2= 0.40 03/306, S3= 0.07 72/046

□ 0
░ 4-8%
▒ 8-16%
■ greater than 16%

Both fabrics consist of measurements of 25 elongate clasts

Figure 44:-
Lithology histograms, Saddle River section

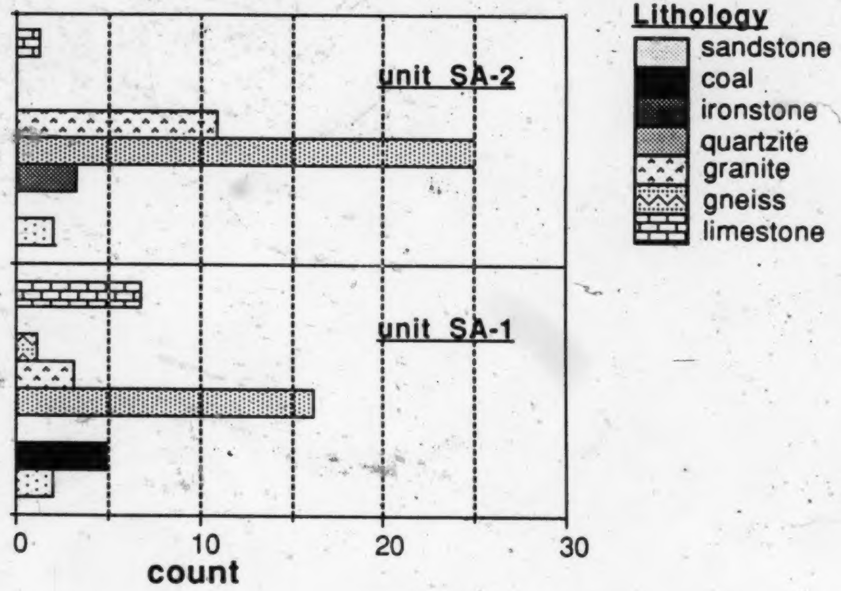
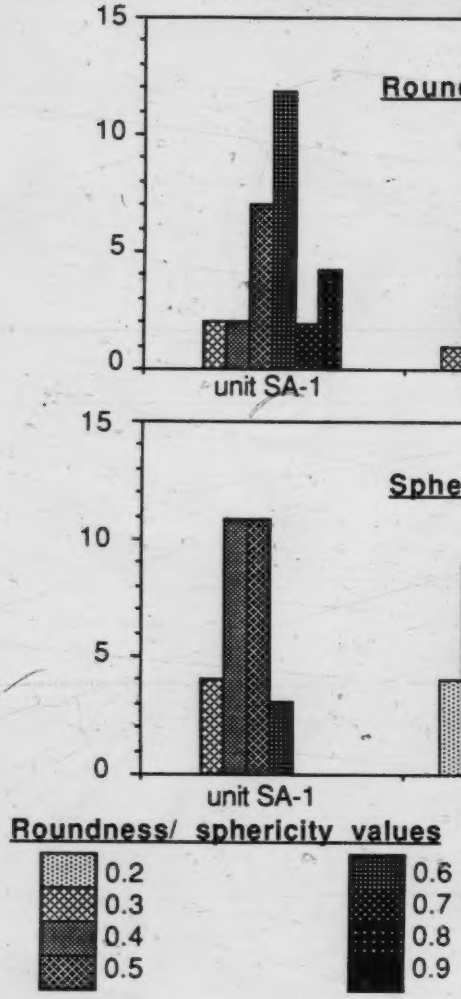


Figure 45:- Roundness and sphericity data, Saddle River section



Roundness and sphericity estimates are by the method of Powers (1953). The number of clasts measured is 29 and 42.

to a lower viscosity, more fluid flow at the top. Such transitions are thought to be common, and occur due to the development of turbulence, and incorporation of water into the flow (Nardin *et al.* 1979; Lowe 1976, 1979).

Thus the likely mechanism of deposition is of sub-aqueous mass movement, with a series of events giving rise to the beds observed. Between mass movement events, suspension settling (and possibly minor turbidity flow) deposited laminated silt and clay. Subsequent flow events loaded and disturbed the fine grained sediments resulting in contortions and discontinuity of lamination.

Unit SA-2:- Description

Unit SA-2 consists of 2.5 m of massive diamicton with many sand, gravel, and silt lenses, and stringers. The unit is recessive but shows some columnar structure.The lenses are mostly fine sand, and are up to 2 m long. The basal contact is sharp and horizontal, and the upper contact gradational. The sand and gravel lenses have sharp, irregular contacts with surrounding diamicton, and are elongate. The clast lithology is similar to unit SA-1, dominated by quartzite, with minor granite, limestone, sandstone, and concretionary ironstone. The high proportion of quartzite results in a high mean roundness (Figure 44, 45, Appendix 6). The grain size distribution of this unit is similar to samples from the base of graded beds of unit SA-1, with 18% sand and 35% clay.

A single 25 stone fabric shows a bimodal fabric, with clasts dipping at low angles, and oriented towards the southwest and west. The fabric is weak, but stronger than that from unit SA-1 (Figure 43).

Unit SA-2- Interpretation

The absence of grading and the presence of many sorted lenses suggests two possible origins for this diamicton, either basal melt-out till or viscous sub-aquatic debris flow.

Basal melt-out tills can contain abundant sorted lenses of sand and silt, but generally possess a well oriented clast fabric parallel to ice flow direction. If this sediment were basal melt-out till, the original fabric must have been disturbed by subsequent events. This might have occurred shortly after deposition by minor mass movement, or be related to the colluviation apparent in the modern valley.

If deposition was by debris flow, then the presence of sorted lenses would indicate deposition by current activity between flow events. The fabric is compatible with viscous, plastic flow (Nardin *et al.* 1979, Lawson 1979a).

Unit SA-3:-Description and interpretation

Unit SA-3 consists of over 2 m of diamicton, more resistant than unit SA-2, and containing fewer sand lenses. It is inaccessible, and thus no fabric or lithology data was obtained. The unit is resistant, and shows well developed columnar structure.

The absence of detailed observations makes interpretation difficult. The similarities to unit SA-2 suggest that unit SA-3 was deposited by either basal melt-out or sub-aqueous mass movement processes.

Saddle River section-discussion

If unit SA-1 is considered to represent deposition by sediment gravity flow into standing water, a source for the material, and a dam for the lake must be sought. The lithology shows abundant clasts of Laurentide provenance, and thus it is likely that the original source of these sediments was till associated with Laurentide glacial deposits. Laurentide ice also provides a means of damming drainage and forming a pro-glacial lake. The source of sediment may have been a "morainal bank" deposited at the grounding line in the manner outlined by Powell (1981, 1984) or supra-glacially deposited till flowing into the lake from the ice surface. The section is presently in a topographic low, and a local gradient away from the ice front would exist, allowing flow of sediment against the regional gradient. The grain size distribution of the base of graded beds is similar to that found in diamictons throughout the area, but the top of the beds contains more silt and less sand. This enrichment in silt may be due to mixing of lacustrine sediment deposited by suspension settling with the original till source.

If this interpretation is correct, then the overlying unit SA-2 may represent proximal glaciolacustrine deposition, with sorted sediments being deposited by sub-aquatic outwash. McCabe *et al.* (1984) report similar sediments interpreted as being deposited sub-aqueously at an ice margin. It is also possible that this unit represents remobilised basal melt-out till, deposited at the base of the ice sheet following movement over the area. Unit SA-3 may represent basal melt-out deposition, and thus the sequence as a whole would represent sediments deposited as an ice front moved into a pro-glacial lake. Alternatively, unit SA-3 may also be the result of sub-aqueous mass movement, in which case the entire sequence might have been deposited during retreat of Laurentide ice. In either case, only one glacial advance is thought to be represented in this section.

Henderson Creek section

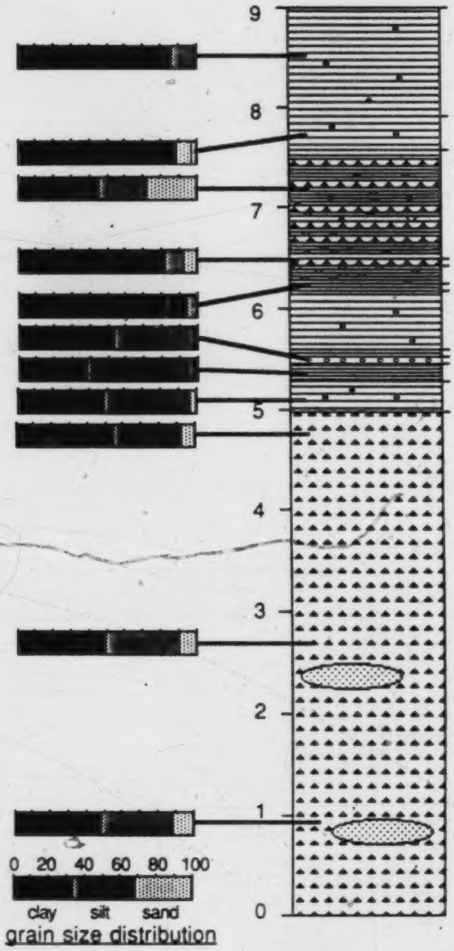
This section is located in a large gully draining south into the valley of Henderson Creek, south of Bonanza. The section exposes nine metres of sediment (Figure 46).

Unit H-1-description

Unit H-1 consists of 5 m of mainly unstratified diamicton. The diamicton has blocky jointing, and contains 5-10% clasts. Large sand lenses, up to 1 m diameter, are found towards the base of the unit, and have irregular boundaries. The sand in the lenses is horizontally bedded and fine grained. The upper 0.5 m of unit H-1 contains discontinuous contorted laminae of silt and clay which dip at shallow angles. Groups of laminae are 2-3 cm thick. This part of the unit appears to contain fewer clasts. The base of the unit is not exposed, and the upper contact with unit H-2 (rhythmically laminated silt and clay) is sharp and undulating.

Samples of matrix and clasts were taken from the top 1.5 m, the middle 2 m and the basal 1.5 m of the unit. Clast orientation measurements were also made at these locations. Grain size data shows little vertical variation, with all three samples containing 10-12% sand, 38-41% silt, and 47-51% clay (Figure 46 and 48). Clast lithology data shows that there is considerable variation (Figure 49), but with all samples dominated by local and quartzite clasts. The mean clast roundness is considerably higher for the basal sample than the other two (Figure 50) and this is probably related to the high proportion of quartzite in this sample.

The fabrics obtained from unit H-1 are plotted in Figure 47. They generally show weak orientations, with most clasts lying at low angles but a significant number with high dip angles. The mean orientations are inconsistent (azimuths of 066, 306, and 323 respectively), and the fabrics are polymodal. The basal fabric is weak with S1 of 0.50, S2 0.37, and S3 0.13. It shows a weak east-west orientation, and a secondary northeast to


9
8
7
6
5
4
3
2
1
0
0 20 40 60 80 100
clay silt sand
grain size distribution

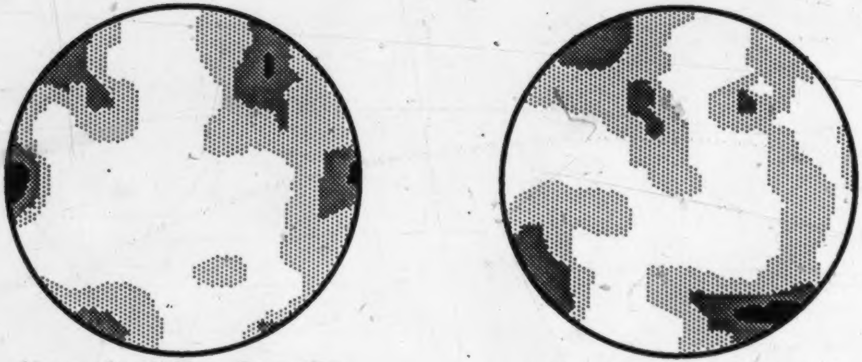
units H-11 and H-12.:- rhythmically bedded silt and clay.

units H-9, 10:- interbedded diamicton and laminated silt and clay.

units H-2 to 8:- rhythmically bedded and laminated silt and clay, normally graded with rare dropstones and intraclasts

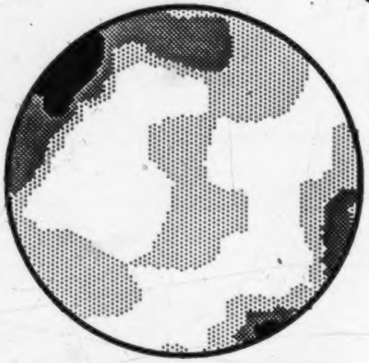
Unit H-1:-Massive diamicton, rare sand lenses up to 1 m wide. Top 0.5 m shows discontinuous contorted laminae of clay.

Figure 46:- Stratigraphy, Henderson Creek section



base of unit H-1. S1= 0.50 11/066, S2= 0.37 17/333, S3=0.13 69/188

middle of unit H-1. S1= 0.43 09/306, S2= 0.33 09/037 S3= 0.23 75/172



top of unit H-1. S1= 0.55 07/323 S2= 0.30 04/054 S3= 0.15 82/172

□ 0
▨ 4-8%
▩ 8-16%
■ greater than 16%

Figure 47:- Clast fabrics, unit H-1 (diamicton), Henderson Creek section

Each fabric consists of measurements of 25 elongate clasts

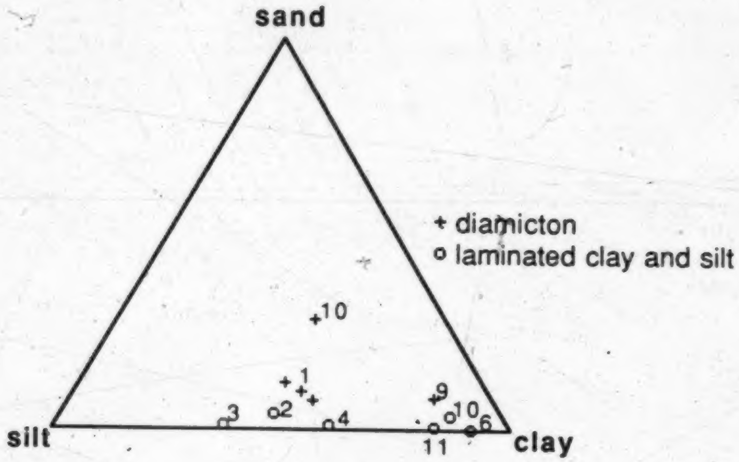


Figure 48:- Ternary plot of results of grain size analysis of samples from Henderson Creek section

Numbers refer to unit numbers (see text)

Figure 49:-
Lithology histograms, Henderson Creek

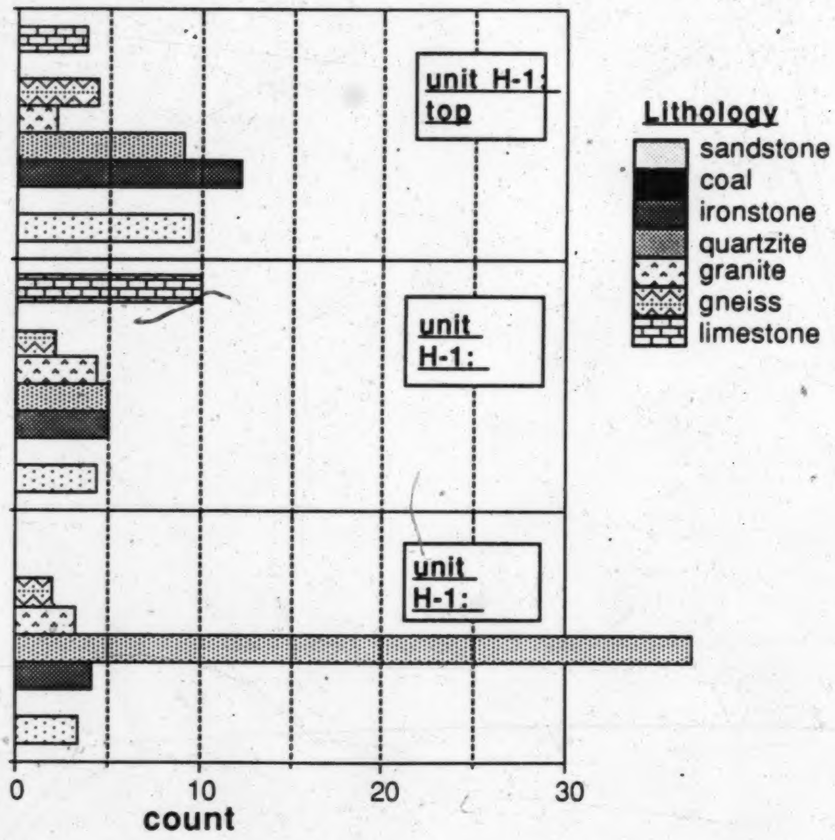
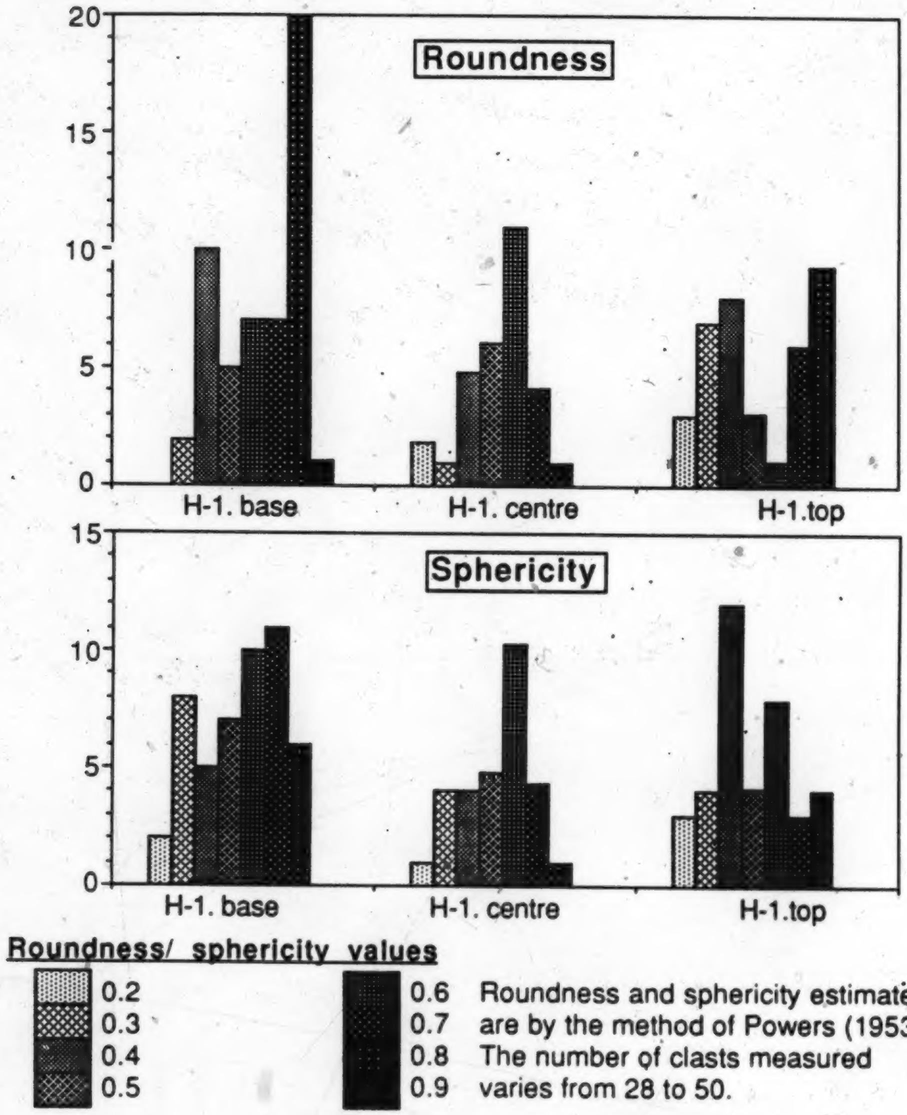


Figure 50:-Roundness/ sphericity estimates, unit H-1, Henderson Creek



Roundness and sphericity estimates are by the method of Powers (1953). The number of clasts measured varies from 28 to 50.

southwest trend. The middle fabric is close to random, with an S1 of 0.43, S2 of 0.33, and S3 of 0.23. The upper fabric is the strongest (although still weak), with S1= 0.55, S2= 0.30 and S3= 0.15. There is a secondary trend transverse to the primary mode.

Interpretation of unit H-1

The poorly sorted matrix with coarse clasts, mostly massive structure, erratic clasts, stratigraphic position, and tabular geometry suggests that unit H-1 was deposited by, or in association with, glacial ice. The generally weakly oriented fabrics precludes deposition as lodgment or undisturbed basal melt-out till (Lawson 1979a, Dowdeswell and Sharp 1986). The unit also lacks other features distinctive of lodgment such as shear planes, fissility or foliation, bullet-shaped clasts and "smudged" clasts (Dreimanis 1976, Müller 1983, Dowdeswell and Sharp 1986).

The presence of sand lenses indicates that flowing water was involved in the deposition of the unit. The shape of such lenses is suggestive of particular environments of deposition (Halderson and Shaw 1982, Shaw 1982, Levson and Rutter 1986). The exposure of lenses in this section is poor, but the irregular margins observed suggests that deformation of the sediment has occurred subsequent to deposition and their general biconvex shape suggests that basal melt-out may have been responsible for deposition of this unit. The silt and clay laminae observed towards the top of the unit were probably deposited in standing water, probably by suspension settling. The discontinuous nature of the laminae suggests that the sediment was remobilised subsequent to deposition.

Although the evidence does not allow an unequivocal interpretation, it is suggested that unit H-1 consists of basal melt-out till remobilised as subaquatic debris flows into a pro-glacial lake. This interpretation is consistent with the poor clast orientations, the distortion of sorted material, and the presence of clay laminae towards the top of the section. The identification of the original sediment as basal melt-out till is tentative, and based on the presence of large sand lenses and the high proportion of locally derived clasts. The clay-rich matrix would render the sediment prone to remobilisation following retreat of ice, especially if the sediment was submerged and saturated. The absence of other structures suggestive of debris flows, such as flow noses, drag folds, and load structures (Dreimanis 1982, Kulig 1985) may be due to the difficulty of observation of such features in a mostly massive sediment. It is possible, however, that the features of the diamicton may have developed by sub-aerial debris flow prior to formation of the glacial lake, or by remobilisation of basal melt-out till in sub-glacial cavities.

Summary and discussion-Stratigraphic Unit C

Examination of the sedimentologic interpretations made of the sections examined in detail allows a better understanding of the regional properties of the diamicton. It is clear that of the possible origins of a poorly sorted, mainly massive, tabular body of sediment found regionally, several can be considered unlikely.

The common features of stratigraphic unit C seen regionally are:-

i. Poorly sorted grain size distribution;

ii. A mixture of locally derived and erratic clasts;

iii. Weak clast fabrics with no apparent relation to regional ice flow;

iv. Inter-stratification with clay and silt laminae;

v. Rare sand silt and gravel lenses, with deformed margins;
vi. Preservation of fragile bedrock clasts;
vii. Tabular geometry, with little lateral facies variation.

Little sedimentologic work was performed by previous workers in the vicinity of Grande Prairie, and Edmonton is the closest area to which comparisons can be made. Shaw (1982, 1987) recognised lodgment till in sections, but found that it was restricted to a thin zone at the base of complex diamicton sequences largely deposited by basal melt-out. Catto (1984) recognised diamictons deposited by basal melt-out and in supraglacial positions. Kulig (1985) demonstrated that diamicton sequences in the Wetaskiwin area were largely deposited by sub-aquatic debris flow, with no lodgment till found. The present study is regional in scope, and sedimentological analysis is less rigorous than the studies referenced above.

Lodgment till possesses a strong unimodal fabric, a pronounced fissility, smearing of fragile clasts, and shear planes (Boulton 1975; Dreimanis 1976; Müller 1983; Dowdeswell and Sharp 1986). These characteristics were not recognised in any exposures in the area and it is likely that lodgment till is rare to absent over most of the area. It is possible that very thin beds of lodgment till such as that described by Shaw (1982, 1987) may be present locally in the field area, but it is certainly not a major diamicton type.

Supraglacially deposited diamicton is thought to be characterised by variable thickness, interbedding and inter-fingering with stratified sediments, a high proportion of erratic and angular clasts, considerable lateral and vertical facies variability, and fabrics variable in both strength and orientation

(Boulton 1971, Eyles 1979). The regional fabric data might be compatible with this interpretation, and other of these features are observed in isolated exposures. Most of the sediment observed was unstratified, with little facies variation, however, and thus it is unlikely that much of stratigraphic unit C was deposited in a supraglacial stagnation environment.

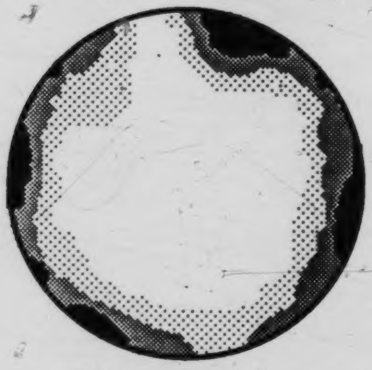
Basal melt-out till shows strong fabrics with low clast dip angles, a tabular geometry, massive structure with lenses and laminae of texturally distinct sediment, and preservation of fragile clasts (Boulton 1975; Dreimanis 1976; Lawson 1979a; Halderson and Shaw 1982; Shaw 1982, 1983). Although stratigraphic unit C shows many of these characteristics, the generally low S1 values and weak fabrics found throughout the area strongly suggest that undisturbed basal melt-out till is not common in the area.

The origin most compatible with the features observed regionally is that of deposition into standing water. Features common to waterlain diamictons include tabular geometry, inter-stratification with laminated silt and clay, lenses of sand and silt, flow noses and load structures from debris flows, dropstones deforming laminae, intraclasts of diamicton and laminated silt, and variable fabric (Powell 1981; Dreimanis 1982; Visser 1983, 1984; Eyles and Eyles 1983; Kulig 1985; Gravenor 1985,1986). The dominant processes in such an environment are rain-out from floating ice, resedimentation of previously deposited material, and current reworking and transport (Eyles and Miall 1984). The relative importance of rain out and resedimentation is controversial, with Gibbard (1980) and Eyles and Eyles (1984) emphasizing rain out, and Evenson *et al.* (1977), Visser (1983), McCabe *et al.* (1984) and Kulig (1985) favouring resedimentation. Fabric can be used as a tool for distinguishing rain-out diamicton from debris flow, but the fabric developed from rain out is poorly understood. Schmoll (1961) described a dropstone fabric from glaciolacustrine sediments, and showed the clasts to have a weak preferred orientation, and to be mostly flat lying. This is mirrored by the fabric obtained in this study (Figure 51) from glaciolacustrine sediments at the Beaverlodge III section. Domack and Lawson (1985) suggested that dropstone fabrics are largely dependent on the substrate that the clast impacts. In the case of "rain out diamicton" they showed that the clast long axes often have a high dip, and with a weak preferred orientation.

In general, it appears that the diamictons observed resemble those deposited by debris flow in a sub-aquatic environment. This is supported by the weak girdle fabric orientations, the tabular geometry, and interstratification with silt and clay. The geomorphic setting is compatible with this interpretation, in that Laurentide ice would dam regional drainage during both advance and retreat. The Beaverlodge River II and Saddle River sections provide evidence of a transition from glaciolacustrine sediment to the deposition of massive diamicton, and there is abundant evidence of debris flow activity in the overlying glaciolacustrine silt and clay of stratigraphic unit D. The source of sediment is probably basal melt-out till, but debris flow would allow for mixing of basal and supra-glacial till, and would also incorporate lodgment till if it were present. It is also possible that "morainal banks" deposited at the grounding line of the ice sheet (Powell 1981) would provide a source of sediment.

It is likely that most resedimentation took place during retreat of the ice, with remobilisation of the till into topographic lows. This would explain the thickness variation between the prairie surface and topographic lows. After retreat of the ice margin, large quantities of saturated poorly sorted clay rich

Figure 51:- Clast fabric from glaciolacustrine sediments, Beaverlodge River III section



Fabric from dropstones in basal units at the Beaverlodge River III section, 29 clasts
S1= 0.54, 04/085, S2= 0.44 , 02/355
S3= 0.02, 86/243

□ 0
░ 4-8%
▒ 8-16%
■ greater than 16%

material would be prone to movement on any slopes greater than 1-2°, and would thus flow to blanket pre-existing sediments and landforms.

This interpretation is valid only for sediment deposited below the probable maximum level of pro-glacial lakes. It is likely that diamicton in the upland areas of the Saddle Hills is mostly basal melt-out till or supraglacial sediments. No good sections were found in these areas so this interpretation remains conjectural. The glacial environment is complex, and can show considerable variation over short distances. Thus the above interpretation is undoubtedly simplistic. More detailed sedimentologic work may allow the identification of areas of basal melt-out or lodgment till.

It is likely that both Cordilleran and Laurentide ice covered the southwestern corner of the Grande Prairie map sheet, yet no clear distinction can be made between diamictons deposited by each source. Mathews (1980) suggested that there is a gradational boundary between the diamictons based on clast lithology, and places the area of confluence to the southwest of Beaverlodge and Hythe. Examination of diamictons east and west of this boundary showed no significant differences in grain size or clast lithology.

To enable examination of diamicton that is of undoubtedly mountain origin, samples were taken from west of Mathews' boundary, where no erratics of Laurentide origin were apparent (sections 86.11 and 86.45). Section 86.43, located west of the boundary, was also sampled but contained rare clasts of Laurentide provenance. The section was located well below palæolake levels, and clasts may have been ice rafted to this locality, without the presence of Laurentide ice. These sections showed massive diamictons with clast lithology dominated by locally derived clasts and quartzite (Figure 24). The texture of these diamictons differs significantly from that found over most of the map area, with low proportions of clay (Figure 40). The only sample from the map area of similar composition was that from section 6.7.8/ 86.19. This section is located in the extreme southwest of the map area and it is possible that the diamicton at this section may be of mountain provenance. The presence of common red granites of Laurentide provenance in diamicton exposed at this location indicates an easterly source, however. This discrepancy can be explained if:-

i. The diamicton is of Laurentide provenance and local variation in grain size distribution of the matrix was caused by ice moving directly over sandstone bedrock (which is exposed directly underlying the diamicton); or

ii. Till deposited by Laurentide ice was reworked into a till deposited by ice from the Rocky Mountains; or

iii Lacustrine sediments containing ice rafted Laurentide clasts were reworked by mountain ice.

Lake sediments formed by damming of drainage by Laurentide ice are found at the top of the section. Thus the third hypothesis is unlikely on the basis of stratigraphic position. The second hypothesis implies either a pre-Late Wisconsinan Laurentide glacial event in the area (which is at variance with the evidence from the pre-glacial sediments found to the north and east) or that Rocky Mountain ice advanced into the lake formed by Late Wisconsinan Laurentide ice, reworking Laurentide till. On balance the first hypothesis is considered most likely.

Thus, it is concluded that the surface diamicton throughout the map area is of Laurentide origin. Laurentide provenance clasts are found throughout the map area, and must have been deposited in the Late Wisconsinan given the chronologic evidence from stratigraphic unit A. There is no evidence of multiple glacial events, with sections showing more than a single diamicton unit being interpreted as being deposited during a single advance. Glacigenic sediments deposited by Rocky Mountain ice have a characteristic clast lithology and grain size distribution, and are not found in the field area.

CHAPTER 6:-STRATIGRAPHY AND SEDIMENTOLOGY - STRATIGRAPHIC UNIT D

General Properties

In the part of the map area lying below 840 m, and overlying stratigraphic unit C, stratigraphic unit D consists of mainly laminated silt and clay, with rare clasts and diamicton interbeds. It has a broadly tabular geometry, thickening towards topographic lows, and the sediments are horizontally laminated, with laminae traceable over many metres. From these general features, the unit is interpreted as being deposited in standing water with low current activity, and an influx of coarse clasts by ice rafting. The glaciolacustrine environment is dominated by sediment gravity flows, particularly turbidity flows, and by suspension settling (Church and Gilbert 1975, Eyles and Miall 1984, Ashley *et al.* 1985, Teller 1987). The detailed properties of stratigraphic unit C vary considerably, and allow a more precise interpretation of the environment of deposition.

Firstly the general properties of the unit will be discussed (thickness and distribution of the unit, grain size distribution, engineering properties, and sedimentary structures), and this will be followed by detailed description and interpretation of several well exposed thick sections.

Thickness and distribution

Examination of the map of the surficial geology (Figure 7) shows that deposition took place in distinct basins. To the south of the Saddle Hills, shoreline features lying between 840 and 810 m; and 710 and 655 m show that two main phases of deposition probably affected low lying areas (below

710 m elevation), whereas only one phase affected areas at an elevation between 840 and 710 m. North of the Saddle Hills, no high level strandline features are observed, and it is suggested that only areas lying below 710 m were affected by lacustrine deposition. Thus the north part of the map sheet shows two distinct basins, separated by the ridge of Blueberry Mountain. The westerly basin forms a minor part of the map area, and is narrow, centred around the Pouce Coupe River. The easterly basin is larger, and surrounds the Peace River. The lowest parts of both basins may have been affected by a second phase of lacustrine deposition related to the strandline features at 590 m described by Mathews (1980), but not recognised in the map area.

Stratigraphic unit D is found widely and commonly forms the surface sediment (map units 5, 6, 7, 8, 9, 11 and 12). The thickness appears to be controlled by altitude, with greatest thicknesses found at lower altitudes. The thickness of the unit was estimated at sections where both top and bottom contacts were exposed, and plotted in Figure 52 against the elevation of the section (estimated from topographic maps). An arithmetic plot shows a curvilinear relationship, and the semi-logarithmic plot presented gives a straight line (correlation coefficient of 0.82). The greatest thicknesses observed were in sections close to the Peace and Pouce Coupe rivers, where up to 30 m of sediment was found.

Grain size distribution

Stratigraphic unit D is dominated by clay and silt (Figure 53). The average values are 1.9% sand, 21.8% silt and 73.5% clay. The proportion of sand can be misleading as, especially to the north of the map area, significant amounts of gypsum were found in the sand sized residue after

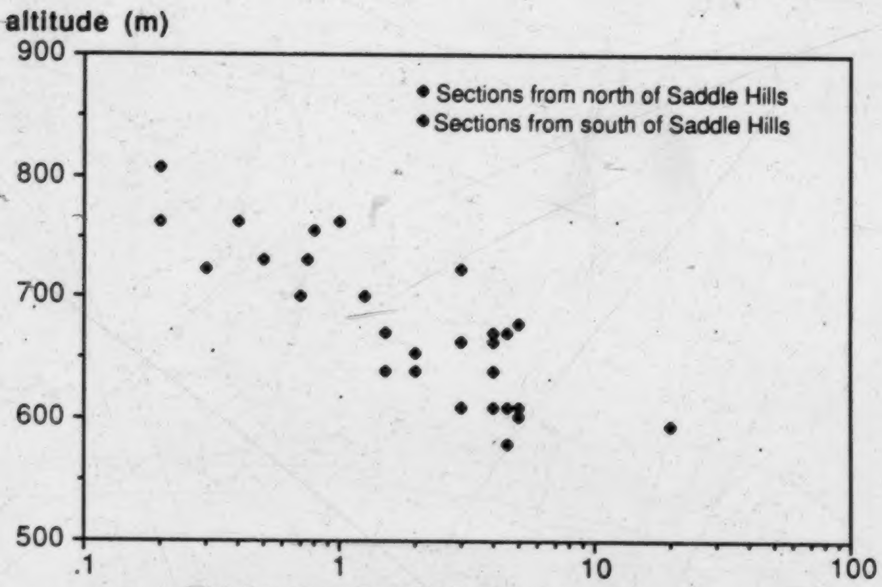
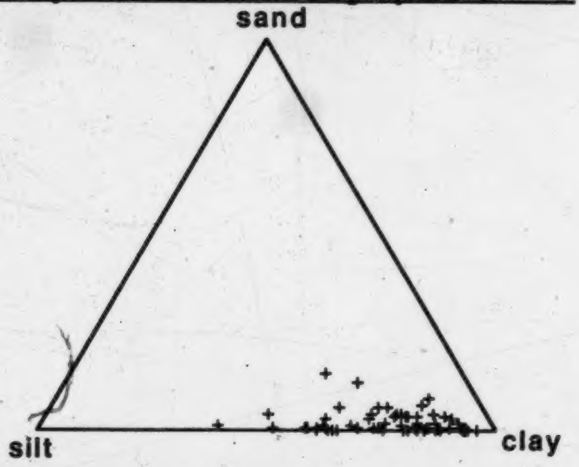


Figure 52:- Plot of thickness of stratigraphic unit D against altitude

This graph plots the logarithm of the observed thickness of stratigraphic unit D against the approximate altitude of the section as estimated from topographic maps.

Figure 53:-Ternary plot of grain size analysis results, stratigraphic unit D



This diagram plots the results of grain size analysis of 63 samples from laminated silt and clay of stratigraphic unit D.

wet sieving. The gypsum forms post-depositionally, probably by crystallization from formation water, and is thus not related to primary depositional processes.

Conventional measures of sorting and mean grain size (Folk and Ward 1957) cannot be used as less than 50% of the distribution is measured by hydrometer analysis. Thus unreasonable extrapolation is required to obtain the statistics required. A grain size envelope is provided in Figure 54.

Three analyses were performed on individual graded laminae by splitting the lamina into top and bottom and performing separate analyses. Samples 86.23 A and B were from a thick couplet with the base consisting of 0.5 to 3 cm of cross laminated and horizontally laminated sand (86.23-A) and the top consisting of massive clay, 0.5 to 1 cm thick. Sample 89.9-b was of couplets of silt and clay with rare dropstones; 86.51-e consisted of silt/ clay couplets with no intraclasts or dropstones. The grain size distributions of the sub-samples are presented in Figure 55.

The results from both 86.9-B and 86.51-E are similar, and show that the base of the couplet gives a very similar curve to that obtained from a bulk sample The top of the couplet has a very similar fine sand/ coarse silt component, but contains a greater proportion of clay. The results of 86.23 A and B support the contrast seen in the field, with no similarity between the curves from top and base. The basal part of the couplet sampled at 86.23 probably represents deposition from a proximal turbidity current, with the top deposited by suspension settling after the decline of current flow. The grading seen in 86.9-B and 86.51-E suggests distal turbidity current activity. The upper part of the couplets was probably dominated by suspension

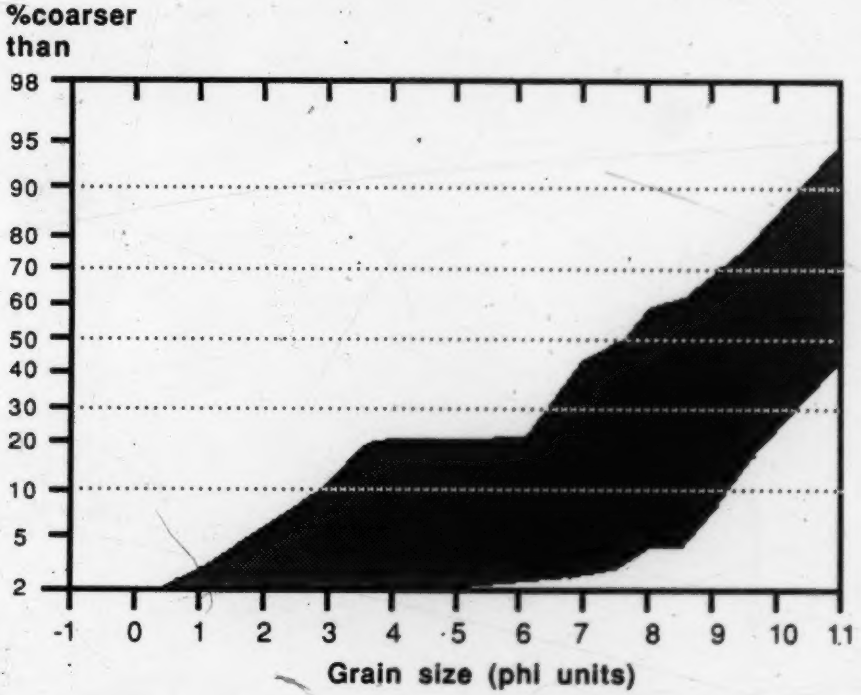
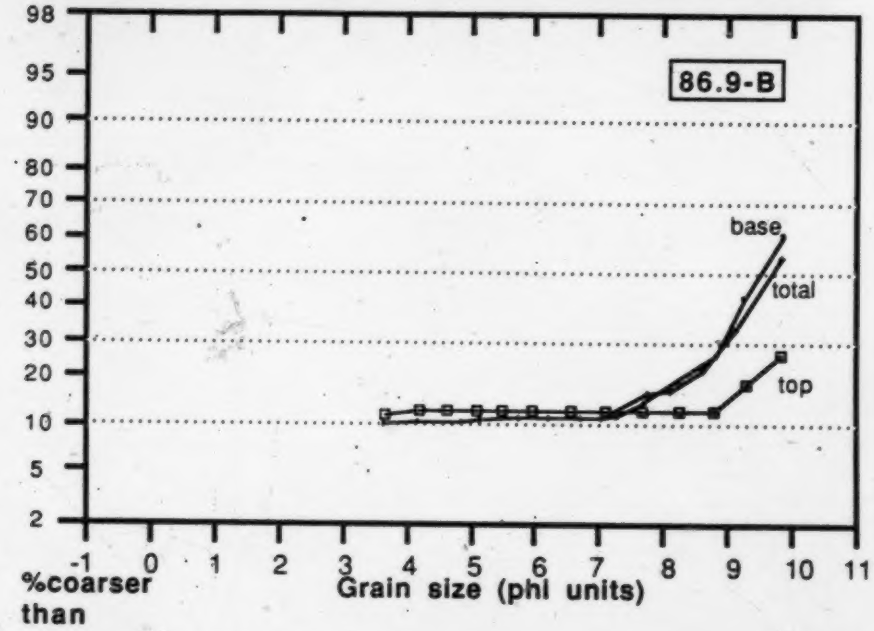
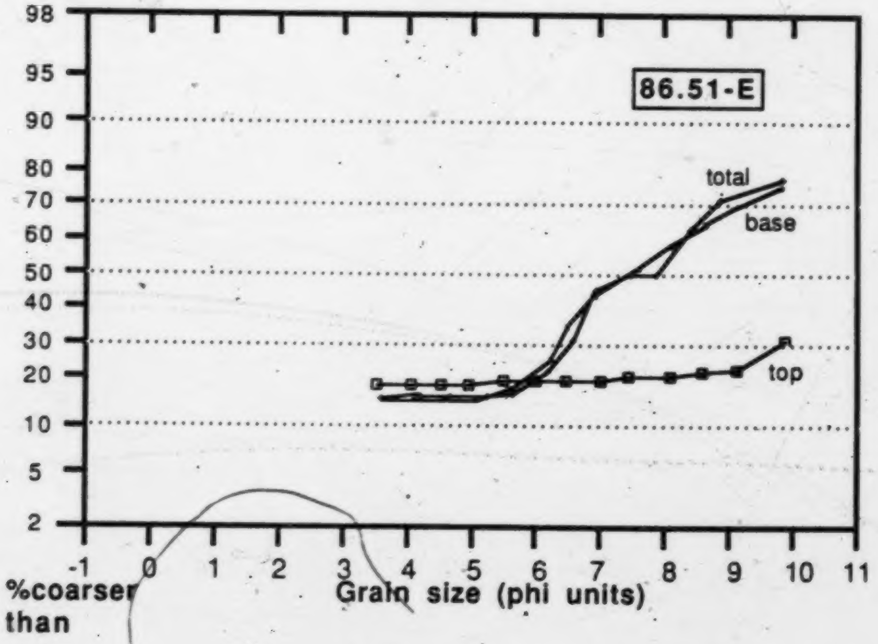


Figure 54 :- Grain size envelope, stratigraphic unit D

All grain size curves from samples of Stratigraphic unit C plot within the envelope shown

Figure 55:- Grain size curves, individual couplets





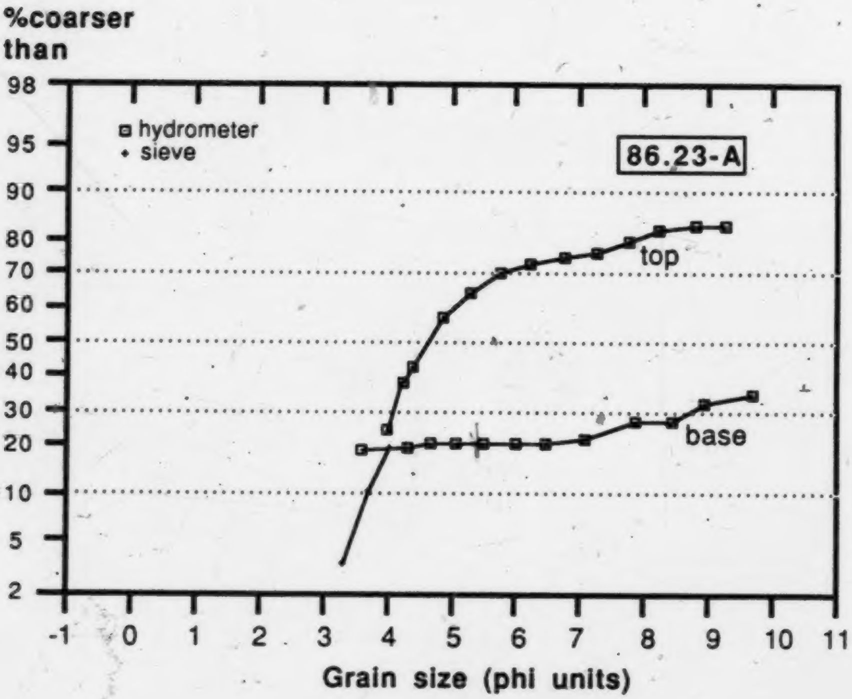


Figure 55 (continued):- Grain size curves, individual couplets settling, but the similarity of the bulk sample curve to the curve from the base suggests that most of the couplet was deposited by current activity. There is no evidence of a sharp break in the laminae indicating cessation of current activity. This suggests that the decline of the turbidity current activity left material in suspension of a similar grain size to that being deposited by the current, which settled out gradually along with other suspended sediment. The fine sand component measured by hydrometer (10-12%) in bulk samples and from top and bottom of couplets is not retained in wet sieving. This inconsistency is probably an artifact of the method used, representing sample lost in analysis, or dissolving of gypsum. The weight of sand retained in wet sieving is less than 1.5% in all analyses from both samples.

Engineering Properties

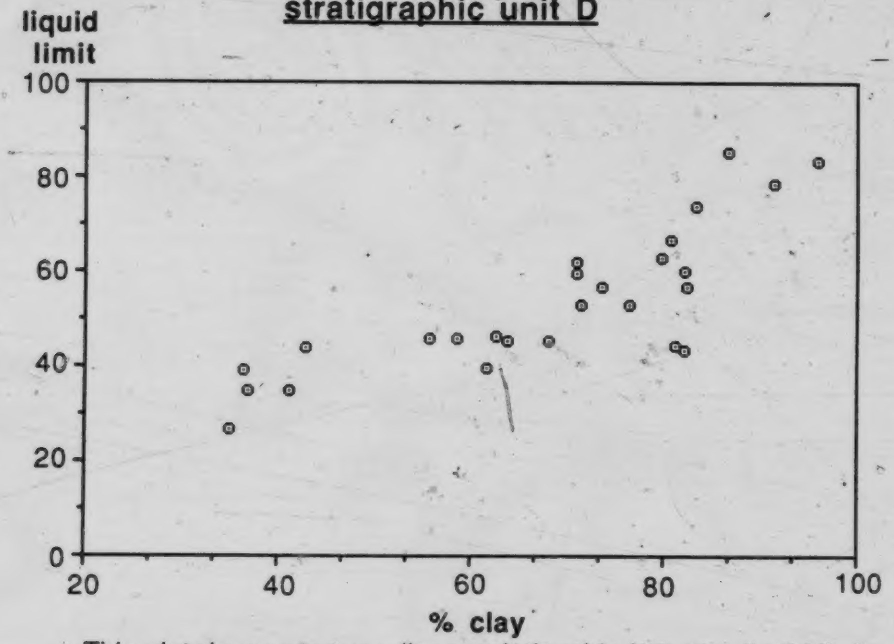
Engineering properties were determined on samples from the Beaverlodge I and III sections in the south of the map area. The results are plotted in Figure 10. Figure 56 indicates that the liquid limit is dependent on clay content of the sample, and thus there is probably little change in clay mineralogy vertically in the sections.

Sedimentary structures

i. Rhythmic horizontal lamination

This is the dominant sedimentary structure observed in stratigraphic unit D, and consists of rhythmically bedded silts and clays, lying horizontally and stratified on a variety of scales. Often a lamina 1-2 cm thick can be seen to be composed of numerous thinner laminae, with up to 17 thin laminae composing a thicker lamina (Plate 16). Each lamina generally has a sharp basal contact, marked by an abrupt coarsening of grain size. Some sections

Figure 56: graph of liquid limit against percentage clay, samples from stratigraphic unit D



This plot demonstrates a linear relationship between liquid limit, and clay content (R=0.82).

Plate 16:- Lamination and graded beds in stratigraphic unit D, sample from sediment association 2, Beaverlodge river III section

(such as 86.23) show thicker couplets with each couplet consisiting of basal silt and fine sand strata up to 3 cm thick and showing internal horizontal and cross lamination, overlain by a massive clay lamina. In some sections, particularly in the southwestern part of the map area (see sections Beaverlodge River I and III below), the upper part of the sequence shows a decline in the clarity of lamination, with beds showing either an indistinct internal lamination, or being apparently structureless.

ii. Grading

Nearly all laminae show normal grading, marked in the field by colour changes and variable moisture retention. The base of strata (silt rich) are buff, whereas the tops (clay dominated) are dark grey. The grading can occur on a variety of scales, with a 1-2 cm thick stratum consisting of 5-17 graded laminae 0.5-1 mm thick. The minor graded laminae show a general but irregular fining trend towards the top of the major stratum. A larger scale fining up is also sometimes discernable, with a sequence of 1-2 cm thick strata, each of which being internally graded, showing a general fining up trend over 10-15 cm. Similar coarsening upwards trends can be noted. In some instances, a graded bed is topped by a sharp contact overlain by a massive clay rich lamina, forming a true silt/ clay couplet.

iii. Flame structures

Flame structures are rarely found in horizontally laminated sediments of this unit, caused by rapid loading by overlying sediments and incomplete dewatering.

iv. Intraclasts

Intraclasts (soft sediment clasts) are common, and can be separated by the relationship of such clasts to lamination. In most examples the diameter of the clast is less than that of the lamina thickness, and does not disrupt lamination. The composition of these clasts usually resembles that of the stratum directly underlying the unit in which it occurs, and the intraclasts are distinguished from the enclosing lamina by slight variations in grain size and colour. They are generally moderate to well rounded. Such intraclasts are probably formed by erosion of a poorly consolidated substrate by current action.

Rarely, the intraclast has a diameter greater than the lamina thickness, and in this case, the underlying lamination is deformed, and the clast is draped by overlying strata. The composition of such clasts is usually poorly sorted diamicton. Their shape is variable, but generally sub-rounded. These clasts are probably dropped through the water column from floating ice calved from the ice front.

iv. Large clasts

Large clasts are anomalously large when compared to the bulk grain size composition of the sediment and consist of bedrock. They deform underlying lamination and are draped by overlying beds (Plate 17). The size varies, but may be up to 40 cm in diameter. Such clasts (usually referred to as dropstones) are deposited when they are released from floating ice, either by melt-out at the base of the ice, or by overturn of a floe (Ovenshine 1970). They fall through the water column and impact the bottom sediments. The orientation of clasts deposited in these sediments is mostly flat lying, but may show preferred orientation. The lithology of such clasts is varied, reflecting the clast composition transported by glacial ice. Clasts with a diameter less than the surrounding laminae may be of similar origin, but

Plate 17:-Coarse clast in stratigraphic unit D. Note deformation of lamination. Trowel is 25 cm long.

cannot be definitely identified as deformation of lamination is not seen.

v. Diamicton interbeds

Diamicton interbeds take two forms. Firstly, diamictons are found as discontinuous beds, 1-30 cm thick. Such beds are usually internally massive, rarely grading upwards to well sorted silt. They pinch out laterally, but can form beds with upwards of 20 m lateral extent. Underlying beds are sometimes deformed presumably due to loading by the diamicton. Clast composition is varied, and similar to underlying glacigenic diamictons of stratigraphic unit C, althouch occasional silt and clay intraclasts are observed. These will be discussed in detail below (Beaverlodge River III and Henderson Creek sections) but probably represent the deposits of subaquatic debris flows from the ice front, or resedimentation of melt-out till.

The second type of diamicton consists of graded beds and laminae with a silt/ clay matrix which contain a high proportion of sand to pebble sized clasts. Commonly the coarse clast component is dominated by silt or clay intraclasts, often forming 20-50% of the bed or lamina. Bedrock clasts are usually present, however, and can dominate the sediment. Clasts are concentrated towards the base of strata, and have a maximum diameter less than the stratum thickness. These are interpreted as being the deposits of turbidity currents, with the source of sediment being glacigenic diamicton and clasts ripped up from underlying silt and clay laminae.

vi. Gravel

Rarely, interbeds of sand and gravel are found within the laminated silt and clay of this stratigraphic unit. The best example is the Albright section (described in detail below) where the coarse sediments are thought to represent the overturn of an ice berg, and dumping of sediment from the surface.

Section descriptions

Seven sections are described below. They represent the best exposed and thickest sequences of stratigraphic unit D found in the map area. The Henderson Creek and Pouce Coupe sections are located in the northwest basin. The Hamelin Creek section is found in the northeastern basin and the Beaverlodge river III, Albright, Beaverlodge River I, and the Bear Creek sections are exposed in the southern basin (Figure 57).

Sections in the northwest of the map area

Two sections are described in the northwest of the map area, exposed along Henderson Creek, and in the Pouce Coupe Valley.

Henderson Creek Section

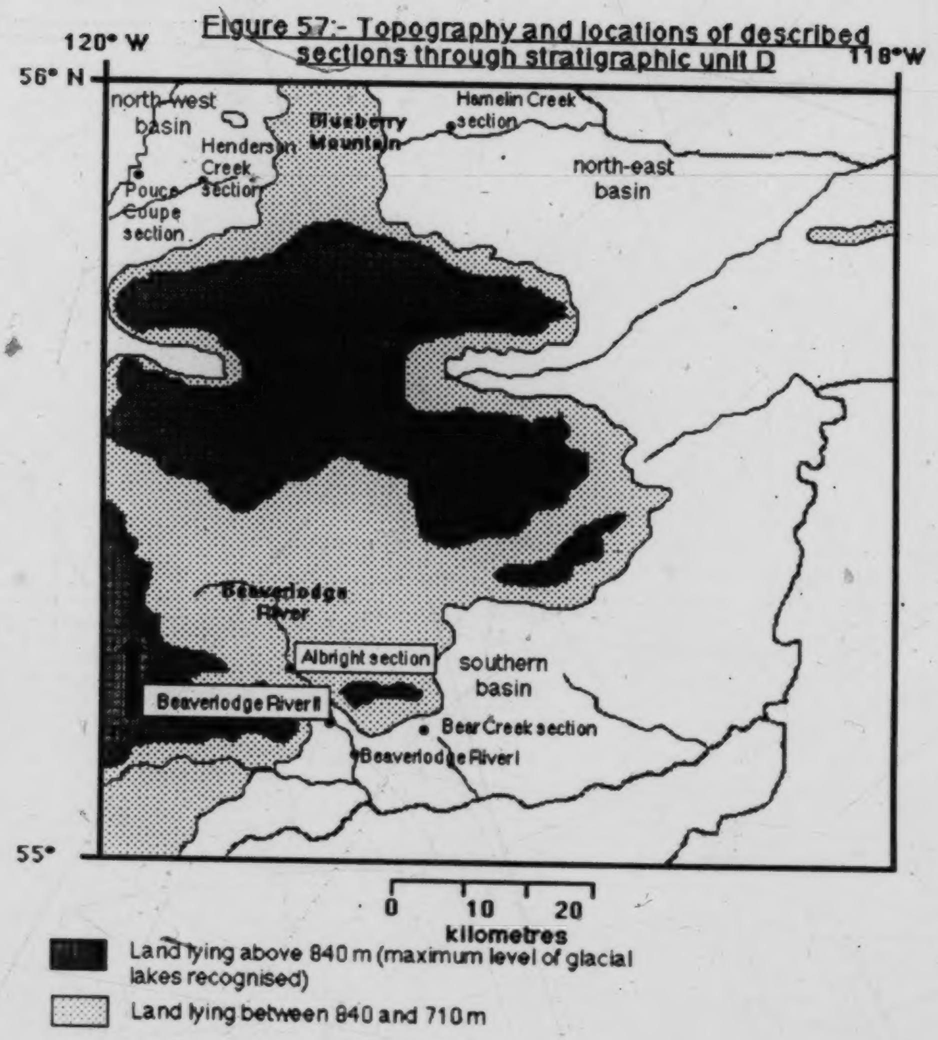
The location and description of the base of this section (unit H-1) has been given above (stratigraphic unit C)(Figures 46 and 48). In this section the upper units, belonging to stratigraphic unit D, will be described and interpreted.

Unit H-2:- Description

Unit H-2, 22 cm thick, consists of 5 poorly defined silt/ clay couplets, each 4-6 cm thick. The lowest overlies unit H-1 (diamicton) with a sharp, undulating contact. The base of each couplet consists of buff silt, indistinctly horizontally laminated. The beds grade normally into massive clay with wisps of silt laminae, and a sharp contact marking the base of the overlying couplet. Rare coarse clasts are found, which appear to deform underlying laminae and are draped by overlying laminae.

Unit H-2 is composed of 48% clay, 47% silt and 5% sand (Appendix 3, Figure 48).

Figure 57:- Topography and locations of described sections through stratigraphic unit D


120° W
118°W
56° N
55°
north-west basin
Henderson Creek section
Pouce Coupe section
Blueberry Mountain
Hamelin Creek section
north-east basin
Beaverlodge River
Albright section
southern basin
Beaverlodge River II
Bear Creek section
Beaverlodge River I
0
10
20
kilometres
Land lying above 840 m (maximum level of glacial lakes recognised)
Land lying between 840 and 710 m

Interpretation

The fine grain size and sorting indicates that unit H-2 was deposited by gentle current activity, and suspension settling. The poorly defined nature of the couplets is due to only slight variations in grain size within each bed. This suggests that either the source of sediment was well sorted; or that transportation by current activity was of sufficient duration to sort the sediment, with coarser material deposited closer to the sediment source. The presence of coarse clasts, probably dropstones, as well as the association with underlying glacigenic diamicton (interpreted as being deposited sub-aqueously), suggests that the environment of deposition was that of an ice-contact glacial lake. The dominant process of deposition in such an environment are sediment gravity flows, and in particular, turbidity currents (Gustavson *et al.* 1975; Church and Gilbert 1975; Ashley 1975; Sturm and Matter 1978; Ashley *et al.* 1985).

The sediments observed show normal grading, indicating declining flow, but do not clearly indicate that turbidity current activity was responsible for their deposition. These sediments probably represent the deposits of distal turbidity currents, with most coarse sediment being deposited up-current. The sediment being carried in the current at this stage would be mostly silt and clay, with little grain size differentiation from sediment settling out of suspension at the same locality. The lamination observed at the base of each couplet probably represents a series of successive turbidity flows, with little suspension settling. The transition upwards represents a decline in turbidity current activity, and sedimentation dominated by suspension settling. The silt laminae seen towards the top of each bed suggest that turbidity current activity occurred throughout the deposition of each bed. The repeated pattern of sedimentation seen throughout the unit indicates that the supply of sediment to the lake was cyclical, with turbidity current activity rising rapidly to a maximum, and declining progressively to a minimum, before rising rapidly again. This could represent an annual cyclicity, but it may indicate shorter term variations in sediment supply due to changes in meltwater supply, slope failures and mass movement related to changes in lake level and other factors.

Unit H-3-Description

Unit H-3 is 18 cm thick, and consists of 32 distinct silt/ clay couplets, 1.5 cm thick at the base of the unit, and thinning upwards to 0.2 cm at the top. The basal contact of the unit is sharp and flat. Each couplet consists mostly of silt, with laminae grading upwards to a clay component, which is less than 0.1 cm thick. The contact between silt and clay in each lamina is gradational. Soft sediment clasts or coarse clasts were not observed. Unit H-3 is composed of 60% silt, 39% clay and 1% sand (Figure 48).

Interpretation

Unit H-3 is interpreted as being deposited in a glaciolacustrine environment, probably closer to the source of sediment than the underlying unit. This is suggested by the higher proportion of silt, indicating a dominance of turbidity current activity over suspension settling, and the greater grain size differentiation seen, indicating that the currents were depositing a greater mixture of grain sizes. The lack of internal lamination in the couplets probably means that each is the product of a single turbidity current. The absence of rip-up clasts means that the currents either were not powerful enough to erode the clay component, or that the clay was not sufficiently consolidated to produce intraclasts, and was incorporated into the current as separate particles. The decrease in couplet thickness up section may indicate a decline in current strength and sediment supply, caused by either a decline in volume of meltwater to the source, or a retreat of the source. The absence of dropstones suggests that ice-rafting was minimal.

Unit H-4:- Description

Unit H-4 is 8 cm thick, and consists of silt/ clay couplets. The basal 4 cm consists of 40 distinct couplets, thinning upwards from 0.4 cm at the base to less than 0.05 cm at the top. The basal couplets have abundant intraclasts of finely laminated clay, up to 0.3 cm diameter. The intraclasts are generally angular. The upper 4 cm contains numerous fine laminae forming couplets, 0.2- 0.3 cm thick at the base, thinning to less than 0.05 cm at the top. Rare intraclasts are observed in this upper half of the unit, and the couplets are increasingly clay dominated up-section.

Interpretation

The sediments of unit H-4 have much the same genesis as those of the underlying unit H-3. The abundant intraclasts observed at the base are interpreted as having been ripped up from the top of the underlying unit. The diameters of the clasts are greater than the thickness of clay observed at the top of unit H-3. It can be deduced that there was a clay stratum of greater thickness at the top of unit H-3, which became sufficiently consolidated to be eroded as clasts by the passage of relatively powerful turbidity currents. Therefore the succession of units H-3 and H-4 represents three cycles of turbidity current activity, with periods of suspension sedimentation occurring as currents declined. The clay strata resulting were eroded by the re-establishment of turbidity current activity. Although it cannot be unequivocally demonstrated, it is likely that each of these cycles represents sedimentation over a year, with turbidity current activity initiated rapidly at spring melt, declining over the melt season, and suspension sedimentation becoming dominant at freeze-up. With re-establishment of current activity in the spring, much of the "winter" layer is eroded, and incorporated as intraclasts.

The absence of "dropstones" suggests that little ice rafted sediment was supplied to the area. This may be due to the direction of prevailing winds directing calved ice away; or indicate that the ice front was some distance from the section at the time of deposition; or that the lake was frozen for much of the year, not allowing movement of calved ice; or a combination of the above.

Unit H-5-description

Unit H-5 consists of 5 cm of finely laminated (less than 0.1 cm) clays, with no intraclasts or dropstones

Unit H-6- description

Unit H-6 consists of 60 cm of silt/ clay couplets. Approximately 60 couplets were counted, showing a pattern of thickening upwards in the basal 40 cm, from 0.3 cm at the base to 2-3 cm. In the upper 20 cm, couplets thin upwards to 0.2-0.3 cm. Rare clasts are observed, but no intraclasts. Grain size analysis shows this unit to be composed of 92% clay and 8% silt.

Unit H-7:- description

This unit consists of 5 cm of finely laminated clays (each lamina being less than 0.1 cm thick. The basal contact is gradational, and the upper contact is sharp.

Unit H-8- Description

Unit H-8 is poorly exposed, and consists of 20 cm of silt /clay couplets, each couplet 0.3-0.5 cm thick. Some couplets contain abundant soft sediment clasts. Each couplet consists of a overall grading from silt to clay, with the lamina being laminated internally. The bulk of each couplet consists of clay.

Interpretation of units H-5 to H-8

This sequence was deposited by a combination of turbidity current and suspension settling processes, with the relative importance of the two processes varying. Unit H-5, mainly clay, was probably deposited by suspension settling, with very little input from turbidity currents. The overlying unit H-6 shows a thickening of lamination upwards, followed by a thinning into unit H-7. Corresponding trends in silt content are also clear. This suggests a progressive increase in turbidity current activity, followed by a gradual decrease, with an input of clay by suspension settling throughout. Unit H-8 contains intraclasts, and higher proportions of silt, and this suggests most of the unit is deposited by relatively powerful turbidity currents, with less suspension settling. Thus a cyclicity in turbidity current activity and strength is apparent in the sequence.

Unit H-9: description

Unit H-9 consists of a 5 cm thick bed of diamicton, containing abundant soft sediment clasts of silt and clay, as well as numerous bedrock clasts. The clasts have a maximum diameter of 1-2 cm, but are generally smaller. The diamicton matrix is silt- and clay-rich compared to the diamicton of unit H-1, and is composed of 8% sand, 10% silt and 82% clay. Grain size analysis is slightly misleading in that the intraclasts (10-15% of the unit) are disaggregated in the process of analysis, and enhance the proportion of fines in the results. The contacts of the diamicton are unclear, but it is stratified, with poorly defined internal laminae, and appears normally graded.

Interpretation

The diamicton of unit H-9 was probably deposited by sub-aqueous sediment gravity flow, as suggested by the association with sediments interpreted as being deposited in a lacustrine environment, normal grading, the presence of abundant rip-up clasts from underlying beds, and internal stratification. The depositing agent was probably a high density turbidity current (c.f. Lowe 1982), and deposition occurred relatively close to the source of the current. The presence of abundant bedrock clasts suggests that the source material was poorly sorted and was probably glacigenic diamicton of stratigraphic unit C. There are two possible mechanisms which could supply such sediment to the area of the section. The first requires the proximity of an ice front, with diamicton being re-sedimented from either the ice surface, or from the grounding line. The second mechanism would involve resedimentation of diamicton deposited on relatively steep slopes, after the retreat of the ice margin. Gravitational instability can be induced by a number of factors, but a drop in the lake level would expose saturated sediments at the lake margin, which would be liable to slope failure. Such failures have been reported in modern lakes with rapid drops in lake level (Liverman 1981, Clague *et al.* 1985, Gilbert and Desloges 1987). In either case resedimentation would take place initially by debris flow, but such plastic flows commonly undergo transition into fluidal flow (Lowe 1976, 1979; Nardin *et al.* 1979).

If the source of sediment gravity flow were the ice front, the bulk of the sediment involved in the flow would be originally of similar composition to diamicton of stratigraphic unit C. Unit H-9 contains much less sand, and much more clay than such diamictons, and resembles the underlying lacustrine rhythmites in composition. It is possible that such a flow could be diluted by incorporation of clay from underlying lacustrine sediments. In the case of slope failure following a drop in lake level, both diamicton, and overlying silt/ clay rhythmites would be involved in the original mass movement. This would result in a mixing of sediment, and is more compatible with the grain size distribution found.

The scarcity of clasts interpreted as dropstones, and the distal nature of the surrounding sediments suggest that the ice margin was not close at this time. Therefore the second mechanism outlined above is thought to be more likely, with a high density turbidity current being initiated following slope failure of previously deposited sediment.

Unit H-10- description

Unit H-10 is 1.2 m thick and consists of interbedded diamicton and silt/ clay couplets. Eight diamicton beds are observed, ranging in thickness from 3-7 cm. The diamictons have a sand rich matrix, and contain a high proportion of stones, up to 3 cm diameter, as well as many soft sediment clasts. Upper and lower contacts are sharp. The beds are laterally continuous over at least 3 m. One diamicton bed was composed of 28% sand, 26% silt, and 46% clay.

Interbedded with the diamictons are approximately 25 silt/ clay couplets, 1 to 4 cm thick. They contain abundant intraclasts, and small bedrock clasts. Grain size analysis shows them to be composed of 3% sand, 10% silt and 87% clay.

Interpretation

The association of diamicton and silt/ clay rhythmites suggests that the diamictons were deposited sub-aqueously. The presence of intraclasts, probably ripped up from underlying beds, sharp contacts, relatively thin beds, and lack of grading suggests that sub-aquatic viscous debris flow was the mechanism of deposition. The arguments given above regarding the source of sediment for diamicton of unit H-9 apply here also. In this case, it is not possible to favour either of the possibilities, as the diamicton of unit H-10 contains a high proportion of sand, and differs from the diamicton of stratigraphic unit C only in its higher clast content. Also there are significant numbers of coarse clasts in the associated silt/ clay couplets, and so an ice margin may have been in the vicinity at the time of deposition of this unit. Thus the debris flows depositing the diamictons were either initiated by slope failure, or were re-deposited from an ice margin. The associated silt/ clay couplets show little systematic thinning or thickening, and are generally thicker than those of the underlying units. It is likely that at this time the section was closer to the source of turbidity currents, resulting in these thicker laminae and beds.

Units H-11 and H-12- Description

These units consist of silt/ clay couplets. Unit H-11, 30 cm thick, consists of 14 couplets, each 0.6 to 3.0 cm thick. Unit H-12, 100 cm thick, consists of a thinning upwards sequence of over 100 couplets, ranging in thickness from 1-2 cm at the base to 0.4 cm at the top. Throughout both units bedrock clasts which deform underlying laminae, and are draped by overlying strata are found sporadically. Grain size analysis of unit H-11 shows it to be composed of 1% sand, 14% silt and 85% clay.

Interpretation

These units are deposited by a combination of turbidity current activity and suspension settling. The relative thickness of the couplets suggests that sediment supply was high compared to underlying units, and the thinning upwards in unit H-12 indicates a decline in sediment supply and current strength.

Discussion- units H-2-to 12, Henderson Creek section

The units show a strong primary cyclicity in sediment supply and current strength and activity. This is typical of the pro-glacial environment, as the discharge of meltwater is the primary control on sediment supply to the glaciolacustrine environment (Church and Gilbert 1975). The most commonly recognised cycle in the glaciolacustrine environment is the annual discharge cycle, with a rapid rise to close to maximum discharge in the spring, and a gradual decline to a minimum approaching freeze-up in the fall. Little meltwater is formed in the winter (Church and Gilbert 1975). This cycle is thought to produce the classic "varve" sequence, with each silt/ clay couplet consisting of a silt dominated base, deposited over the summer by turbidity currents, grading normally, with an abrupt contact leading to a massive clay component, deposited by suspension settling in the winter (Antevs 1925, Kuenen 1951). Lacustrine sequences in the Peace River area have been interpreted as being composed as varves, and varve counts have been used to determine the life-span of the lake (Henderson 1959; Jones 1961; Mathews 1978, 1980). If the rhythmical sedimentation observed in this section is assumed to represent annual events, then the sediments represent at least 500 years of deposition (this represents a minimum as the fine laminae of units H-5 and H-7 are ignored).

This is a very simplistic interpretation. The laminae and beds do not show the classic varve structure, as each consists of a consistent normal graded stratum, with no clear break between a summer and winter layer. It is more likely that each consists of the deposits of a single turbidity current, or a sequence of several turbidity currents, between which little suspension settling took place. The sediments observed are mainly distal, with little sand, and show none of the structures typical of proximal turbidites (Bouma 1962; Walker 1984).

Thus either the section was not close to the source of turbidity currents, and only powerful currents would reach the site; or only weak turbidity currents were generated. In this case it is likely that the "semi-seasonal" discharge cycle of Church and Gilbert (1975) is that represented in the sediments, with high discharge events occurring sporadically through the melt season. These high discharge events would be more common at spring break-up, when meltwater supply is generally at a maximum, and decline in frequency through the year. Suspension settling continues throughout. In this case, the thinning up sequence of rhythmites may represent the deposition of a single year, with the "winter" component either eroded by the subsequent current activity in the spring, or represented by the thinnest laminae. Using this interpretation, the sediments represent 10 to 30 years of deposition, depending on the exact interpretations of units H-2, H-10 and H-11.

An alternative interpretation which must be considered in this case is that thickening/ thinning trends may not solely represent variations in input from a single source. It is quite possible for the sediments to represent deposition from more than one source of turbidity currents, and also the source of such currents might be variable in position, with a fluctuating ice margin. Thus a thinning sequence might represent the retreat of the ice front, and an increasing distance between the input of meltwater to the lake, and the section. The relatively consistent thinning/ thickening trends seen does suggest that a single source of turbidity currents dominates sedimentation, but variation in the distance of the source cannot be discounted. The main conclusion to be drawn, however, is that the rhythmites may not be interpreted as simple varves, and therefore that the lake may have existed for a much shorter time than would be suggested by that interpretation.

There are two possible interpretations for the origin of the diamicton interbeds seen towards the top of the section. These diamictons were probably the result of debris flow and high density turbidity current activity either from the ice margin (implying a re-advance of ice) or by slope failure following a drop in lake level. The section is located on a gentle northward slope, but only 5 km from a steep gradient leading to strandlines marking the lake edge. There is no stratigraphic evidence for a re-advance elsewhere in the northwest of the map sheet, and other sections exposing this stratigraphic unit do not show sediments that might be interpreted as ice-proximal. Thus these diamictons probably were deposited as the result of mass movement following a drop in lake level.

The altitude of the section is approximately 640 m and therefore it was submerged by the set of lake levels recognised between 710 and 655 m (Chapter 2, map unit 12). However, it lies above the lower lake margin at 570 m recognised by Mathews (1980).

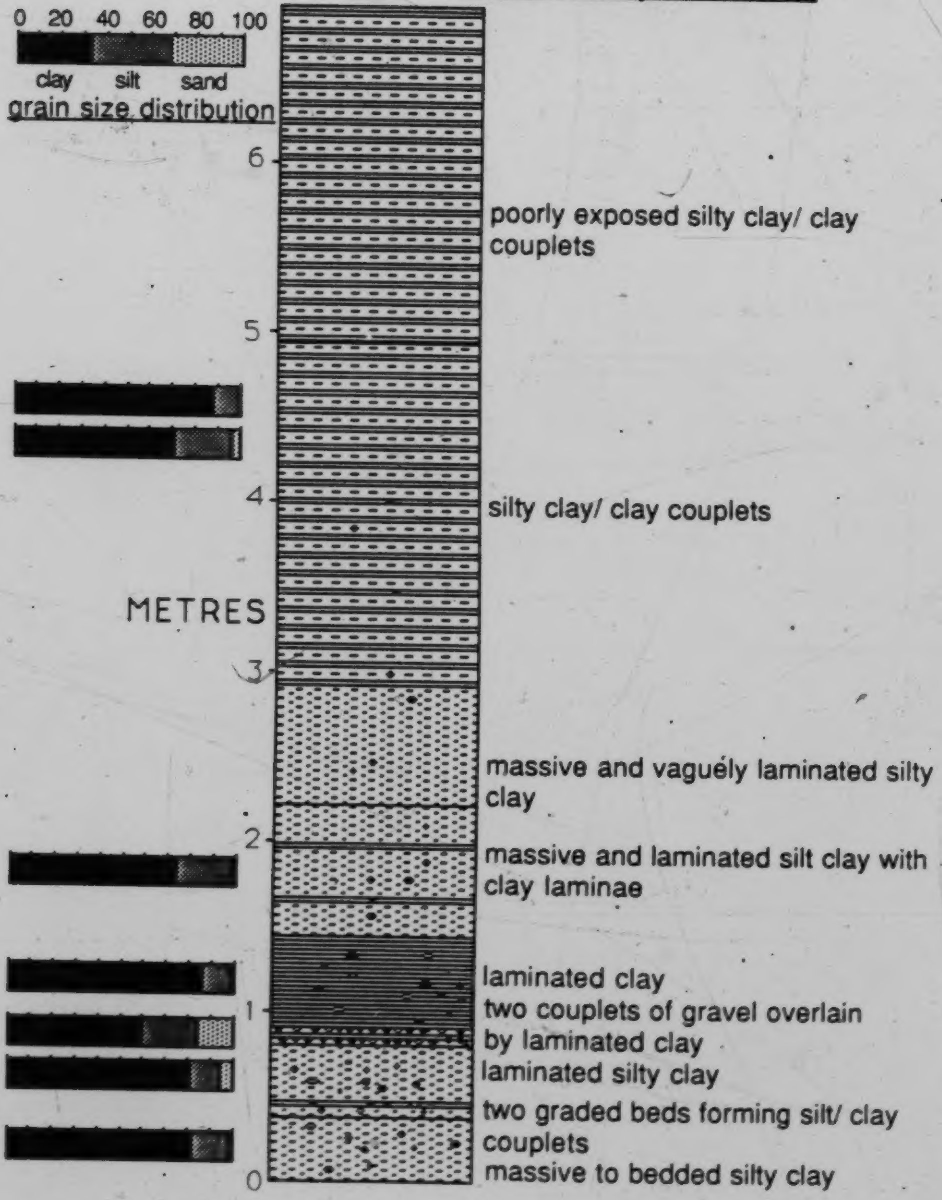
Pouce Coupe Section

This section is exposed on the eastern edge of the Pouce Coupe Valley (Appendix 1). Sections on the western edge of the valley show up to 25 m of diamicton of stratigraphic unit C overlying bedrock, and overlain by thick sequences of silt and clay of stratigraphic unit D. Diamicton is not well exposed at this section, but 10-15 m of bedded silt and clay was examined in detail (Figure 58).

Description

The base of the section shows two beds of massive to vaguely horizontally bedded silty clay, showing little grain size variation, but containing soft

Figure 58:- stratigraphic column, Pouce Coupe section


0 20 40 60 80 100
clay silt sand
grain size distribution
METRES
0
1
2
3
4
5
6
poorly exposed silty clay/ clay couplets
silty clay/ clay couplets
massive and vaguely laminated silty clay
massive and laminated silt clay with clay laminae
laminated clay
two couplets of gravel overlain by laminated clay
laminated silty clay
two graded beds forming silt/ clay couplets
massive to bedded silty clay

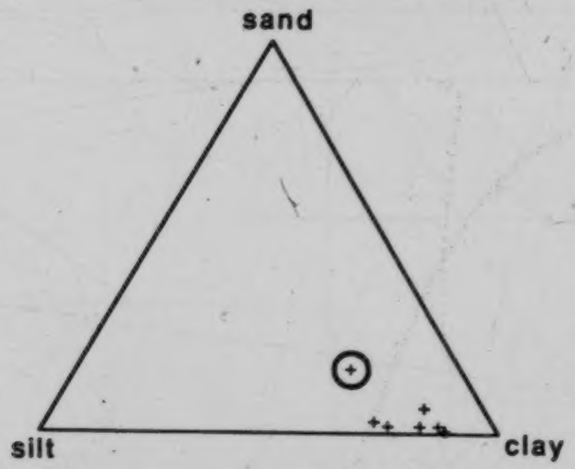
sediment clasts of clay, and bedrock clasts. The beds are composed of 2% sand, 16% silt and 82% clay (Figure 59). These strata, 25 cm thick, are overlain by three normally graded beds with massive silt at the base, grading up into laminated clay. Bedrock clasts and intraclasts are common, and bedrock clasts deform underlying laminae, and are draped by overlying laminae. The basal two beds are each approximately 5 cm thick, and the upper lamina is 1 cm thick.

Overlying this is a sequence of 35 cm of laminated silts, with laminae ranging in thickness from 0.2 to 1 cm in thickness, and generally show a vertical thickening. Each lamina is normally graded, but shows little internal grain size variation. Both soft sediment and bedrock clasts are common, and can deform underlying stratification. The composition of laminae of this sequence is 7% sand, 13% silt and 80% clay (Figure 59, Appendix 3).

This sequence is overlain by two beds, 5- 7 cm thick, each of which consists of a basal intraclast gravel, 3-4 cm thick, overlain by laminated clay. The contact between the two sediment types is sharp. The gravel is matrix supported and poorly sorted, and contains abundant intraclasts and bedrock clasts up to 1.5 cm diameter. The matrix is relatively sandy (16% sand, 24% silt and 60% clay) and shows no apparent grading or bedding. The clays are laminated, with laminae 0.1-0.2 cm thick, and the laminae gently undulate with an amplitude of 1-2 cm. The laminae contain abundant bedrock clasts.

The overlying unit consists of 50 cm of laminated clay, with each lamina 0.1 to 0.2 cm thick. The laminae lie generally horizontally, but are slightly deformed, undulating with an amplitude of 1-3 cm. Grain size analysis shows the unit to be composed of 2% sand, 12% silt and 86% clay. Both bedrock and soft sediment clasts are common, and both show deformation of underlying laminae and are

Figure 59: Ternary plot, grain size results, Pouce Coupe



All samples are of laminated silt and clay, apart from a single sample from intraclast gravels (circled) draped by overlying laminae. Overlying this is 1.5 m of vaguely laminated silt and clay, forming a resistant band. Bedrock and soft sediment clasts are less common, rare towards the top. Several clay laminae 0.5- 1 cm thick are found spaced throughout the unit. Grain size analysis shows the base of this unit to be composed of 2% sand, 23% silt and 75% clay.

These sediments are overlain by a sequence of 12 couplets, each 6-20 cm thick, with a total thickness of 2 m. Each couplet consists of a base of vaguely laminated to massive silty clay, with a gradational contact into finely laminated clay. The silty clay at the base usually forms over half the couplet and varies in thickness from 5 to 15 cm. Stones are found only rarely, and no intraclasts are apparent. Grain size analysis shows the base of each couplet to consist of 1% sand, 23% silt, and 76% clay, whereas the top is 1% sand, 11% silt, and 88% clay.

Higher in the section, the sediments are poorly exposed and inaccessible, but appear to show a sequence of couplets resembling that described above, each couplet 15-20 cm thick. Coarse clasts are not apparent in the upper part of the sequence, which is 3- 5 m thick. From a distance it is clear that the sediments in the section are deformed, undulating with an amplitude of up to 1 m, and a wavelength of 10 -20 m.

Interpretation

The fine grain size, common dropstones, and rhythmic sedimentation suggests that the sequence as a whole was deposited in a glaciolacustrine environment, with turbidity currents and suspension settling the dominant agents of deposition. Apart from the two intraclast dominated gravel beds, the sediments show little sand, and high proportions of clay. This suggests that suspension settling was the main process operating, with turbidity currents being weak and the section distant from the source of the currents. Ice rafting of clasts decreases in importance up section, as indicated by the decline of dropstones. Although the majority of intraclasts were probably ripped up from underlying beds, some soft sediment clasts deform underlying lamination. This dropstone style of deformation indicates that these clasts were ice rafted. It is possible that these represent incorporation of lacustrine sediments into seasonal lake ice by freezing on at lake margins in the winter (c.f. Shilts and Dean 1975, Dionne 1979).

The base of the section does not show a well defined cyclicity, or clear lamination. This suggests that a source of glacial meltwater was not close to the section at this point, as such a source would show a marked cyclicity in discharge and sediment supply (Church and Gilbert 1975). The transition between stratigraphic unit C and D is not observed here but 3 km west (at section 86.46), 2 m of stratified diamicton interbedded with silt laminae, is successively overlain by 1.5 m of distinctly laminated silt/ clay couplets, and a sequence similar to that exposed in the Pouce Coupe section. The stratified diamicton is of stratigraphic unit C, and was probably deposited by subaqueous resedimentation of till. The overlying sediments of stratigraphic unit D show little evidence of ice proximal deposition. This implies a rapid retreat of the ice front in this area. With retreat of the ice front towards the northeast, direct meltwater input from the ice front declined in importance, and it is likely that sediment was supplied to the lake by streams from the Saddle Hills and from west of the map area. These streams would still probably have a source dominated by meltwater, with its characteristic discharge cyclicity, but would travel some distance before discharging into the lake (c.f. Catto 1987a). Over this distance, sorting of the sediment would occur, with coarse sediment deposited, and also the amplitude of the discharge cyclicity would decline (Church and Gilbert 1975, Ringberg 1984). Thus although the stream would enter the lake as a turbid underflow, the strength and frequency of such inflow would not show such a great variation in current strength and sediment supply as would inflow direct from meltwater.

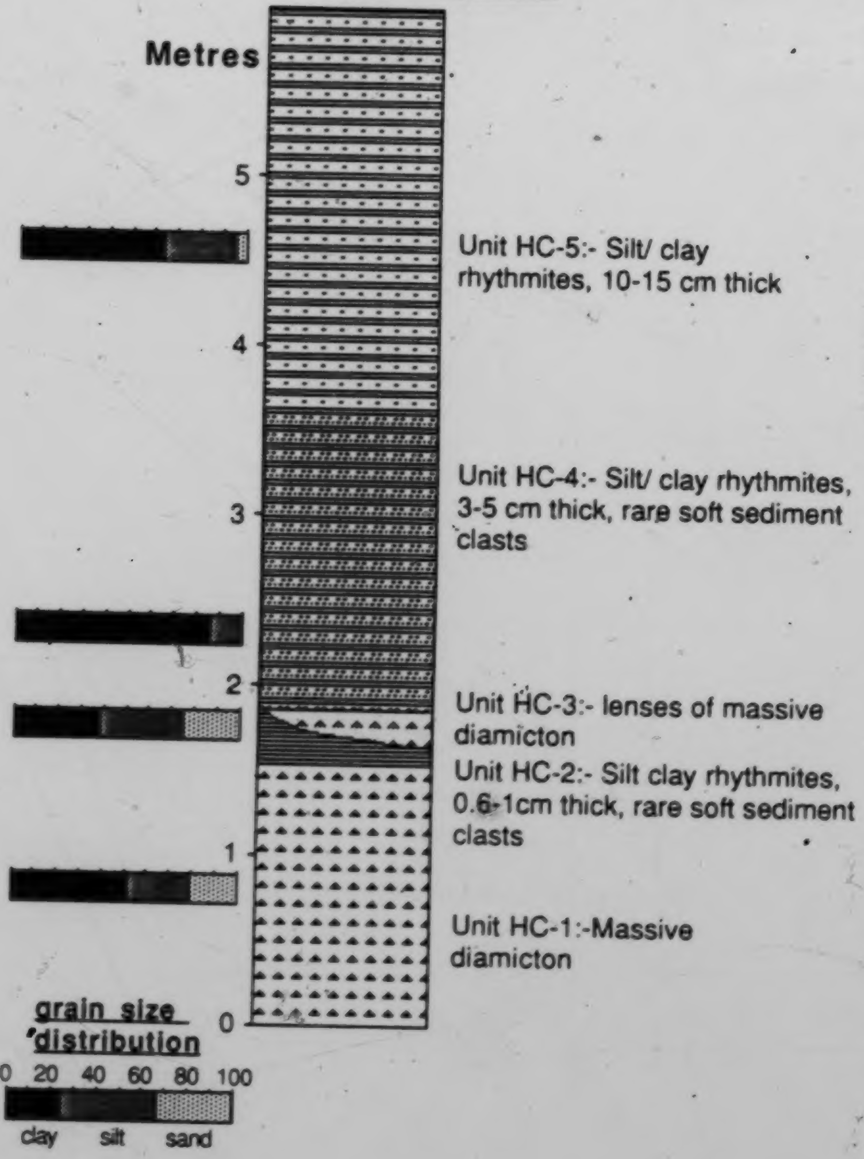
Up-section, the two gravel/ clay couplets can be interpreted in a similar manner to the diamicton interbeds in the Henderson Creek section. It is likely that the gravel was deposited as debris flow or high density turbidity currents were initiated following slope failure, with clay deposited by suspension settling.

The upper part of the section shows a rhythmic alternation between massive to laminated silty clay, and laminated clay, with each couplet relatively thick. This alternation may represent an annual cycle, with fluctuating current activity over the summer, and mainly suspension settling activity in the autumn and winter. Therefore, the sequence as a whole probably represents less than 60 years of deposition, whereas an assumption that each couplet is a varve would suggest a much greater time period. The upper part of the sequence shows no dropstones, suggesting the ice margin was some distance away at this point.

Hamelin Creek Section

The Hamelin Creek section is located in the northeastern basin, on the eastern slopes of Blueberry Hill at an altitude of approximately 610 m. It exposes over 5 m of sediment belonging to stratigraphic units C and D (Figure 60).

Figure 60:- Stratigraphy, Hamelin Creek Section


Metres
5
4
3
2
1
0
grain size distribution
0 20 40 60 80 100
clay
silt
sand

Unit HC-5:- Silt/ clay rhythmites, 10-15 cm thick

Unit HC-4:- Silt/ clay rhythmites, 3-5 cm thick, rare soft sediment clasts

Unit HC-3:- lenses of massive diamicton

Unit HC-2:- Silt clay rhythmites, 0.6-1cm thick, rare soft sediment clasts

Unit HC-1:-Massive diamicton

Unit HC-1-Description

Unit HC-1 consists of 1.5 m of diamicton, mainly structureless, but with some indistinct banding in the uppermost 20 cm. It contains a mixed lithology, including quartzite, granite, chert, limestone, and sandstone (Appendix 4). Clasts show a moderately oriented fabric trending southwest with low dips (Appendix 2). It is composed of 21% sand, 27.5% silt and 51.5% clay.

Interpretation

Unit HC-1 is representative of stratigraphic unit C, and was deposited in association with glacial ice. Following the arguments outlined above, it is likely that it was deposited as basal melt-out till, and may have undergone resedimentation.

Unit HC-2- Description

This unit, 3-15 cm in thickness, overlies a sharp flat contact, dipping gently to the west. It consists of 4 to 8 graded silt/ clay couplets, containing soft sediment clasts which are elongate, and lie with the long axis flat. The variability in thickness is due to an erosive upper contact, which truncates the laminae of this unit.

Interpretation

Unit HC-2 was probably deposited in a glaciolacustrine environment by a combination of turbidity current action and suspension settling. The soft sediment clasts were ripped up from underlying beds by turbidity current flow, and deposited as the current declined. The absence of sharp internal contacts in the strata, and progressive normal grading suggests that each lamina represents the deposits of a single turbidity current, with a gradual decline and replacement by suspension settling as the primary agent of deposition. There are no bedrock clasts, indicating that ice rafting was unimportant at the time of deposition.

Unit HC-3- Description

Unit HC-3 consists of discontinuous lenses of diamicton, 10-20 cm thick, and of up to 80 cm horizontal extent (Plate 18). The basal contacts are sharp, and truncate underlying laminae of unit HC-2. Several such lenses are observed at the same stratigraphic level. There are no internal structures apparent, and the diamicton contains clasts up to 10 cm diameter of variable lithology. It is composed of 25% sand, 37% silt and 38% clay (Appendix 3).

Interpretation

Possible origins of diamicton interbeds in a lacustrine sequence have been discussed above (Henderson Creek section). In this case the lensoid geometry, erosive basal contacts, and lack of internal structure suggests that these beds were the deposits of sub-aquatic plastic debris flows. The source of sediment was probably resedimented material from a nearby ice margin, or resedimentation of glacigenic diamicton deposited in an unstable position. Instability might be induced by a change in lake level. Neither underlying nor overlying units show evidence of ice rafting, nor of proximal turbidity currents, suggesting that the ice margin was not in the vicinity at this time. The composition of the unit is similar to that of unit HC-1, and the intervening unit HC-2 is only 3-15 cm thick. The section is located in a topographic low, surrounded by moderate slopes suggesting that debris flows may have originated following local slope failure. All lenses occur at one stratigraphic level, suggesting a single event, such as a drop in lake level, triggered debris flow activity.

Plate 18:- Units HC-1 to 4, Hamelin Creek section. Knife is 20 cm long.

Unit HC-4-Description

Unit HC-4 consists of 1.5 m of rhythmically bedded silty clay and clay, with 35-40 graded beds each 3-5 cm thick. Thinning or thickening trends are not seen. Elongate soft sediment clasts are common, but bedrock clasts are absent. The unit is composed of 13% silt and 87% clay.

Interpretation

Unit HC-4 was deposited in a similar manner to unit HC-2, with turbidity current activity prominent, and associated suspension settling. Ice rafting was unimportant, and the lack of sand in the sediment suggests that the section is located distal to the source of turbidity current activity. Each stratum probably represents the effects of a single turbidity current or a series of turbidity currents rather than an annual cycle.

Unit HC-5- Description

This unit is relatively poorly exposed, but consists of a 2 m sequence of rhythmically bedded silt and clay, with beds 5 cm thick at the base, thickening upwards to 10-15 cm. No soft sediment or bedrock clasts were observed. Grain size analysis shows that the unit is composed of 6% sand, 31% silt, and 63% clay (Appendix 3)

Interpretation

Unit HC-5 is interpreted as being deposited in a similar manner to units HC-2 and HC-4 above. The thickening upwards trend and coarser grain size reflects either an increase in current strength and sediment supply, or that the source of current flow was closer to the section at this time.

Discussion- Hamelin Creek Section

The section exposes a sequence that shows a progression from diamicton deposited in association with ice to sediments deposited in a lacustrine environment, with little evidence of ice rafting. The turbidity currents depositing graded beds were of sufficient strength to rip up clasts and their deposits appear to become more proximal up section. The typical sedimentary sequence expected with ice retreat is that of glacigenic diamicton, overlain by proximal glaciolacustrine deposits, showing decreasing influence from the ice margin up-section, as the source of meltwater, dropstones, and sediment retreats. The succession exposed at the Hamelin Creek section is best explained by considering a rapid retreat of the ice margin, possibly without the initial establishment of a pro-glacial lake. When the position of the ice front stabilised, a lake formed, but the Hamelin Creek section was some distance away from the ice front. As the lake became established, the main source of sediment was turbidity currents initiated by underflow of sediment laden streams entering the lake from the west, rather than from the retreating ice front. Thus, as the lake level dropped, the source of sediment moved closer to the section, resulting in the thicker rhythmites, and coarser grain size seen. The section is located 15 km from the presumed initial western shoreline of this part of the lake basin, and the upland area of Blueberry Mountain may have retained some ice, which on melting would still produce the cyclicity in discharge typical of glacial meltwater streams. The section is located at an elevation of approximately 610 m, and was thus submerged throughout the period of lake stability indicated by shorelines at elevations between 710 m and 655 m seen to the east of the section.

Altogether, 64 rhythmic strata are observed in the section, but it is unlikely that these represent annual cyclicity. It is probable that the lacustrine sediments in this section were deposited in a comparatively short time, but with no clear evidence of the period of cyclicity, it is not possible to estimate the duration.

Elsewhere in this northeastern part of the lake basin, similar sequences are exposed. At low elevations, close to the Peace River, relatively coarse grained sediments are exposed at the surface. None of these sections are well enough exposed to merit a full description and interpretation

Section 17.7.3 is located south of the Peace River and northwest of Rycroft (Appendix 1). It is associated with the hummocky topography of map unit 8, and shows 3 metres of cross laminated clayey silts, indicating current flow to the east. These sediments have a composition of 1% sand, 77% silt and 22% clay. Similar sediments are seen in section 17.7.4, 2 kilometres east at a similar altitude. The Peace River section has been described in Chapter 2 (map unit 9), and contains cross-laminated and laminated sand and silt, indicating current flow to the south and east.

These sections lie at approximately 565 metres, the lowest altitudes in the map area apart from the modern river valleys. The sediments exposed probably represent lacustrine deposition close to the inflow of the re-established Peace River in a deltaic or pro-delta environment. The interpreted direction of current flow is parallel to the modern river, and the grain size is indicative of more powerful current flow than that depositing the majority of sediments of stratigraphic unit D. Cross lamination of various types is common in glaciolacustrine deltas, and pro-delta sediments (Jopling and Walker 1969, Stanley 1974, Shaw 1975).

Section descriptions, Beaverlodge River

The Albright section is found at an elevation of approximately 730 m just west of the hamlet of Albright. The Beaverlodge River III section is at an elevation of 690 m, 10 km southeast along the river, and the Beaverlodge River I section is a further 5 kilometres southeast at an elevation of 685 m (see stratigraphic unit C above and Figure 57).

Beaverlodge River III Section

This section shows 8 m of sediment dominated by silt and clay (Plate 17). Rather than describe each of the 75 units designated in the field, they have been grouped into sediment associations. There are four distinct associations discussed here from the base of the section upward (Figures 61 and 62). Grain size data is presented in Figure 63.

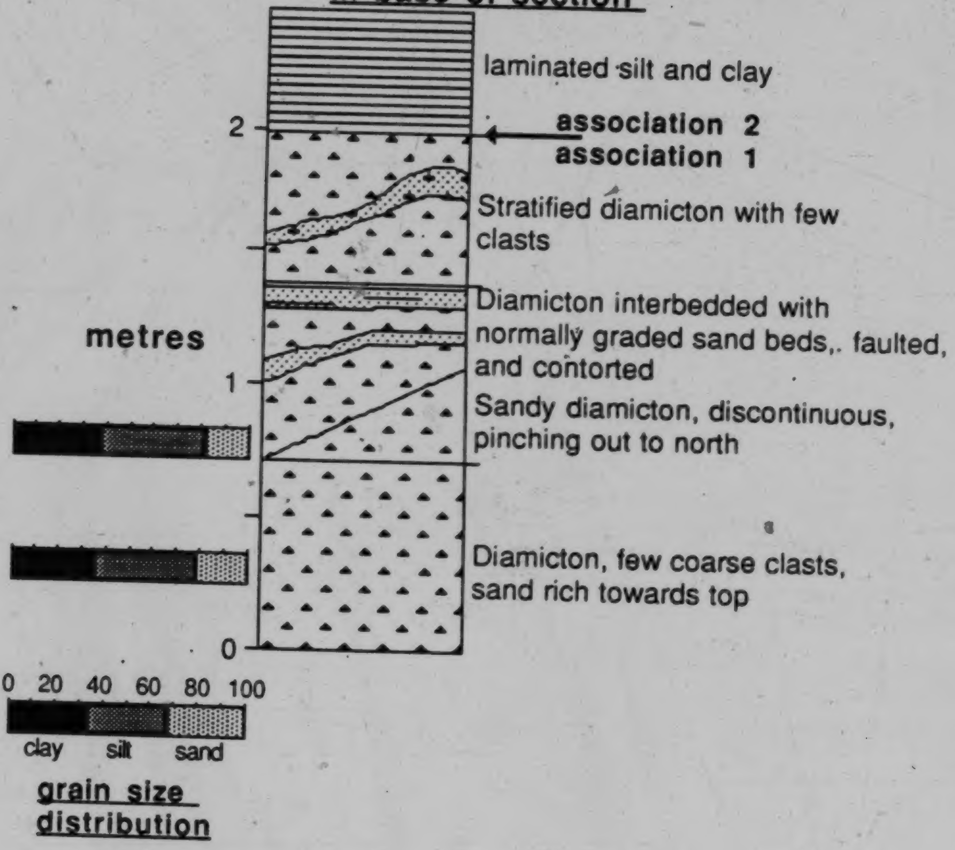
Sediment association 1- description

At the base of the section is a thin sequence of complexly interbedded diamicton and sand. Diamicton constitutes 80% of the association. Diamicton beds can be structureless but are usually stratified, and are often discontinuous. Compared to diamicton of stratigraphic unit C, these diamictons have a lesser coarse clast component, and are more sandy in texture. Clasts up to 30 cm long axis were observed, and show a varied lithology, with sandstone, quartzite, granite, and chert prominent. The sand beds are often normally graded, and consist mostly of well sorted fine sand. Sand beds are up to 20 cm thick, and can fine upwards into silt and clay. The sequence as a whole shows considerable lateral and vertical variation.

Interpretation

This association is representative of sedimentation in a lake adjacent to an ice margin supplying abundant sediment and meltwater. The diamictons are interpreted as being the result of debris flows, on the basis of the sharp lower contacts and the discontinuous nature of the strata. Pinching out to the north

Figure 61:- Stratigraphy, Beaverlodge River III base of section


laminated silt and clay
2
association 2
association 1
Stratified diamicton with few clasts
Diamicton interbedded with normally graded sand beds,. faulted, and contorted
metres
1
Sandy diamicton, discontinuous, pinching out to north
Diamicton, few coarse clasts, sand rich towards top
0
0 20 40 60 80 100
clay
silt
sand
grain size distribution

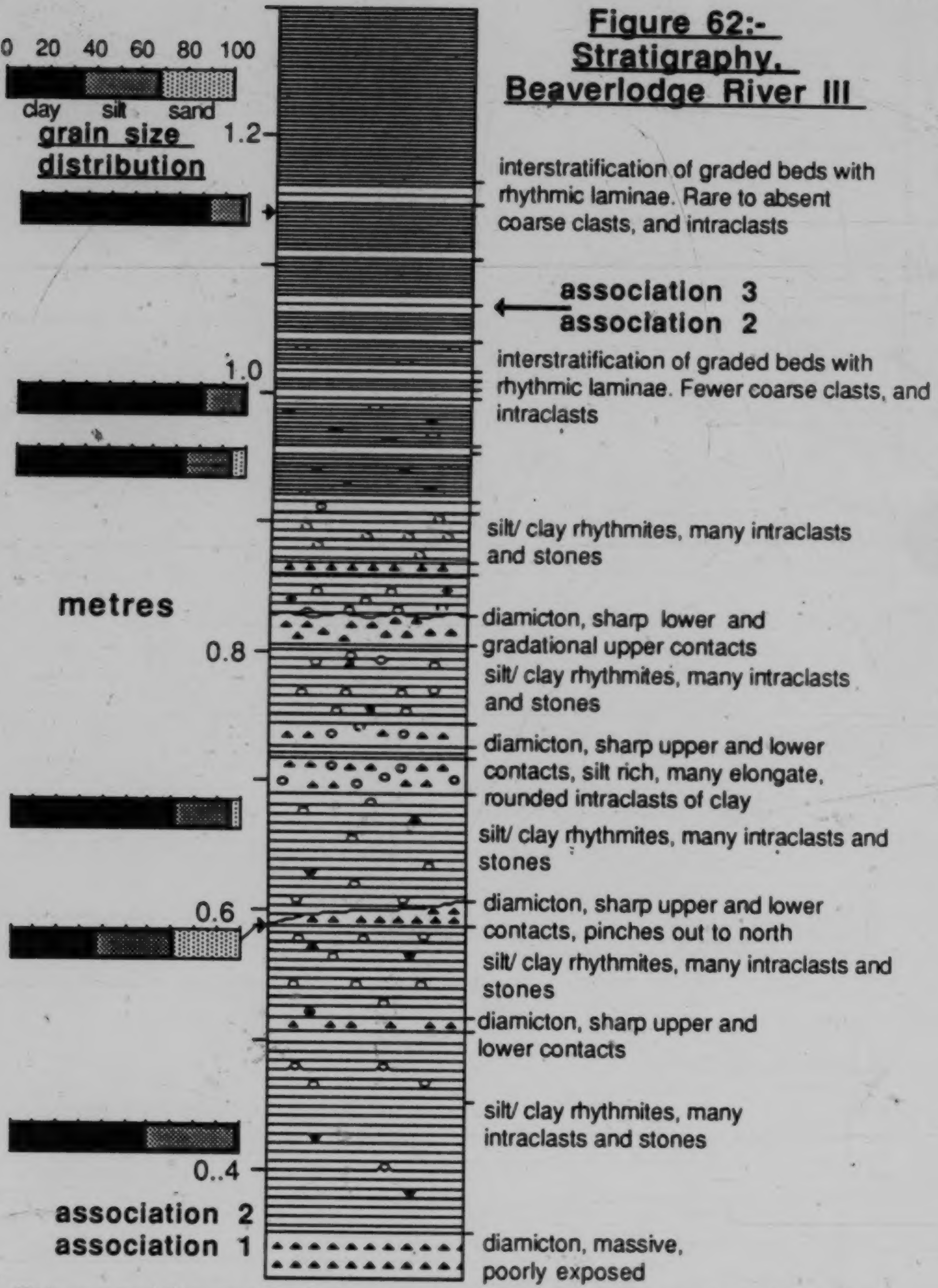


Figure 62:- Stratigraphy, Beaverlodge River III

0 20 40 60 80 100
clay silt sand
grain size distribution
metres
1.2
1.0
0.8
0.6
0..4
interstratification of graded beds with rhythmic laminae. Rare to absent coarse clasts, and intraclasts
association 3
association 2
interstratification of graded beds with rhythmic laminae. Fewer coarse clasts, and intraclasts
silt/ clay rhythmites, many intraclasts and stones
diamicton, sharp lower and gradational upper contacts
silt/ clay rhythmites, many intraclasts and stones
diamicton, sharp upper and lower contacts, silt rich, many elongate, rounded intraclasts of clay
silt/ clay rhythmites, many intraclasts and stones
diamicton, sharp upper and lower contacts, pinches out to north
silt/ clay rhythmites, many intraclasts and stones
diamicton, sharp upper and lower contacts
silt/ clay rhythmites, many intraclasts and stones
association 2
association 1
diamicton, massive, poorly exposed

This part of the section is located 25 m south of the section shown in Figure 61, and the contact between sediment associations 1 and 2 is used to correlate between them

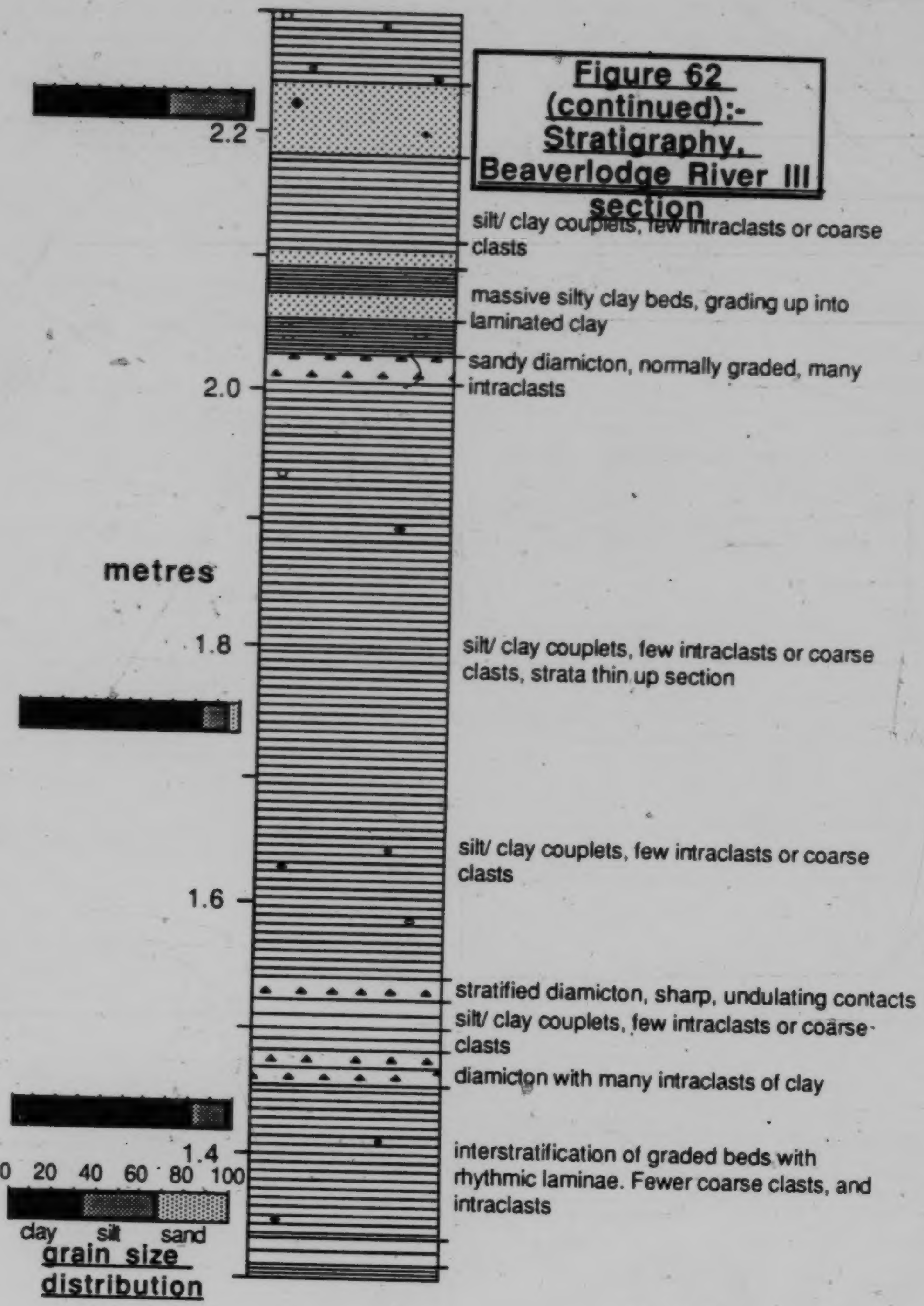


Figure 62 (continued):- Stratigraphy, Beaverlodge River III section

2.2
silt/ clay couplets, few intraclasts or coarse clasts
massive silty clay beds, grading up into laminated clay
sandy diamicton, normally graded, many intraclasts
2.0
metres
1.8
silt/ clay couplets, few intraclasts or coarse clasts, strata thin up section
silt/ clay couplets, few intraclasts or coarse clasts
1.6
stratified diamicton, sharp, undulating contacts
silt/ clay couplets, few intraclasts or coarse clasts
diamicton with many intraclasts of clay
1.4
interstratification of graded beds with rhythmic laminae. Fewer coarse clasts, and intraclasts
0 20 40 60 80 100
clay
silt
sand
grain size distribution

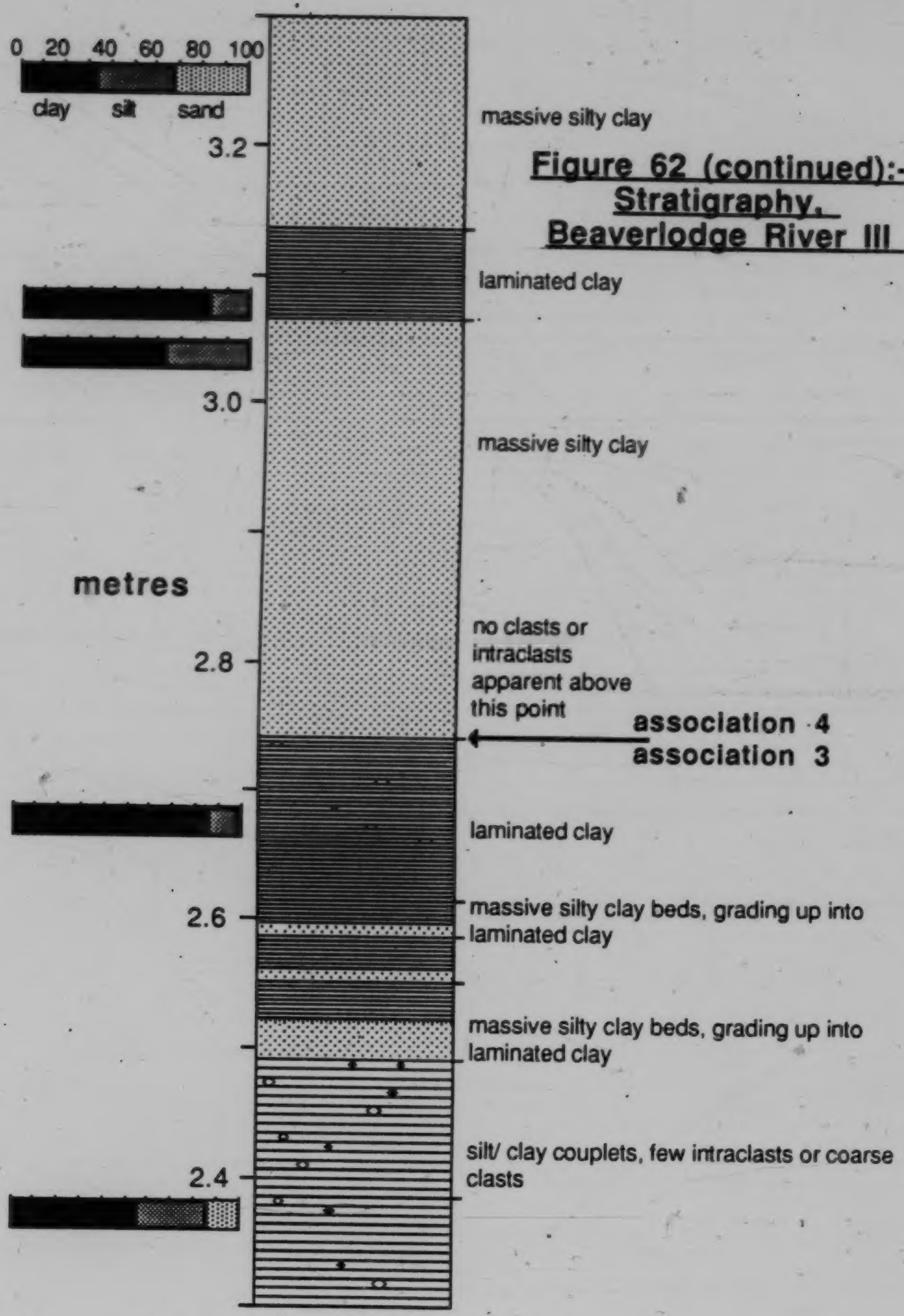

0 20 40 60 80 100
clay
silt
sand
metres
3.2
3.0
2.8
2.6
2.4
massive silty clay
laminated clay
massive silty clay
no clasts or intraclasts apparent above this point
association 4
association 3
laminated clay
massive silty clay beds, grading up into laminated clay
massive silty clay beds, grading up into laminated clay
silt/ clay couplets, few intraclasts or coarse clasts

Figure 62 (continued):- Stratigraphy, Beaverlodge River III

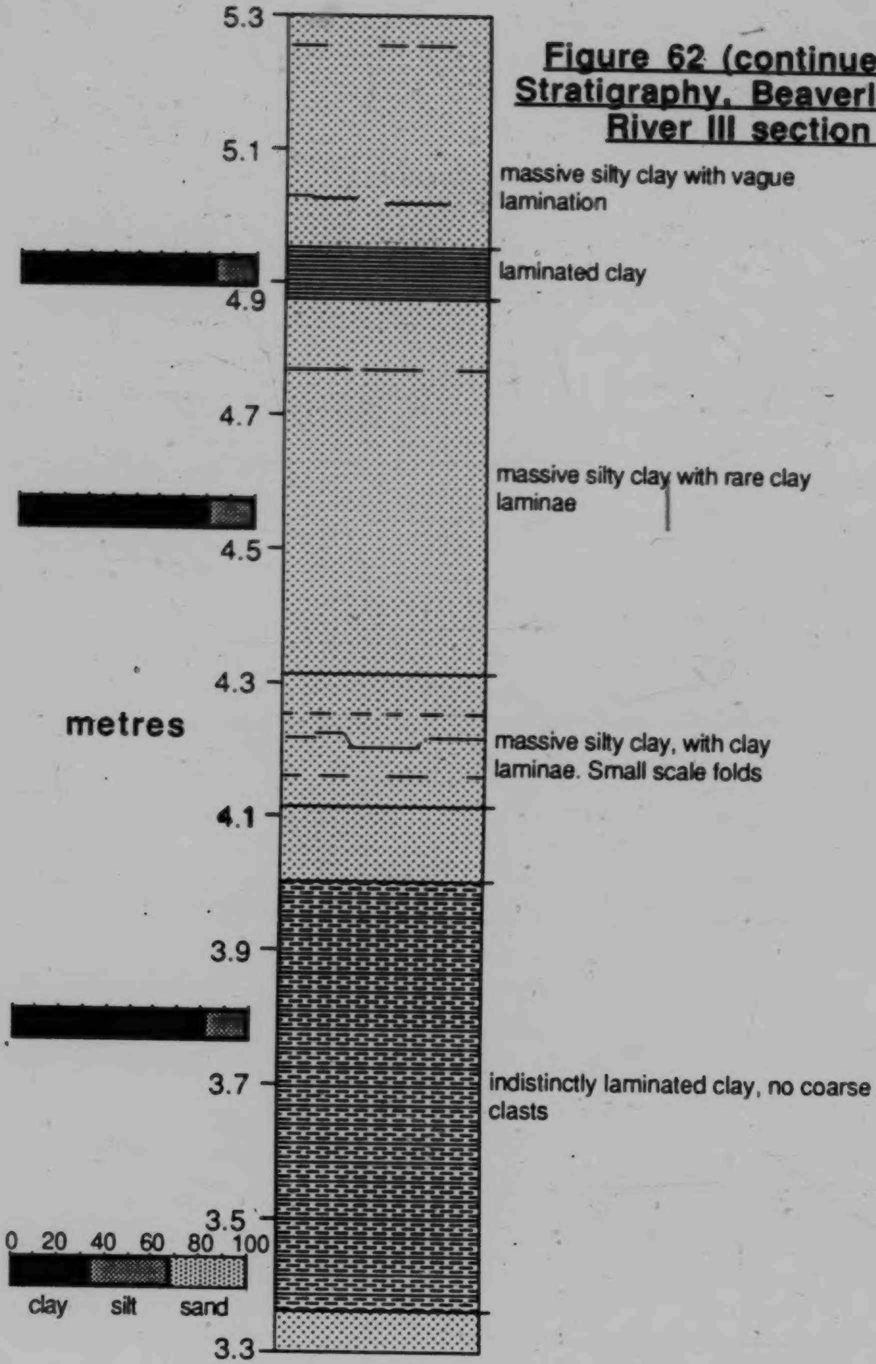

5.3
5.1
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
3.3
metres
0 20 40 60 80 100
clay
silt
sand

Figure 62 (continued):- Stratigraphy, Beaverlodge River III section

massive silty clay with vague lamination

laminated clay

massive silty clay with rare clay laminae

massive silty clay, with clay laminae. Small scale folds

indistinctly laminated clay, no coarse clasts

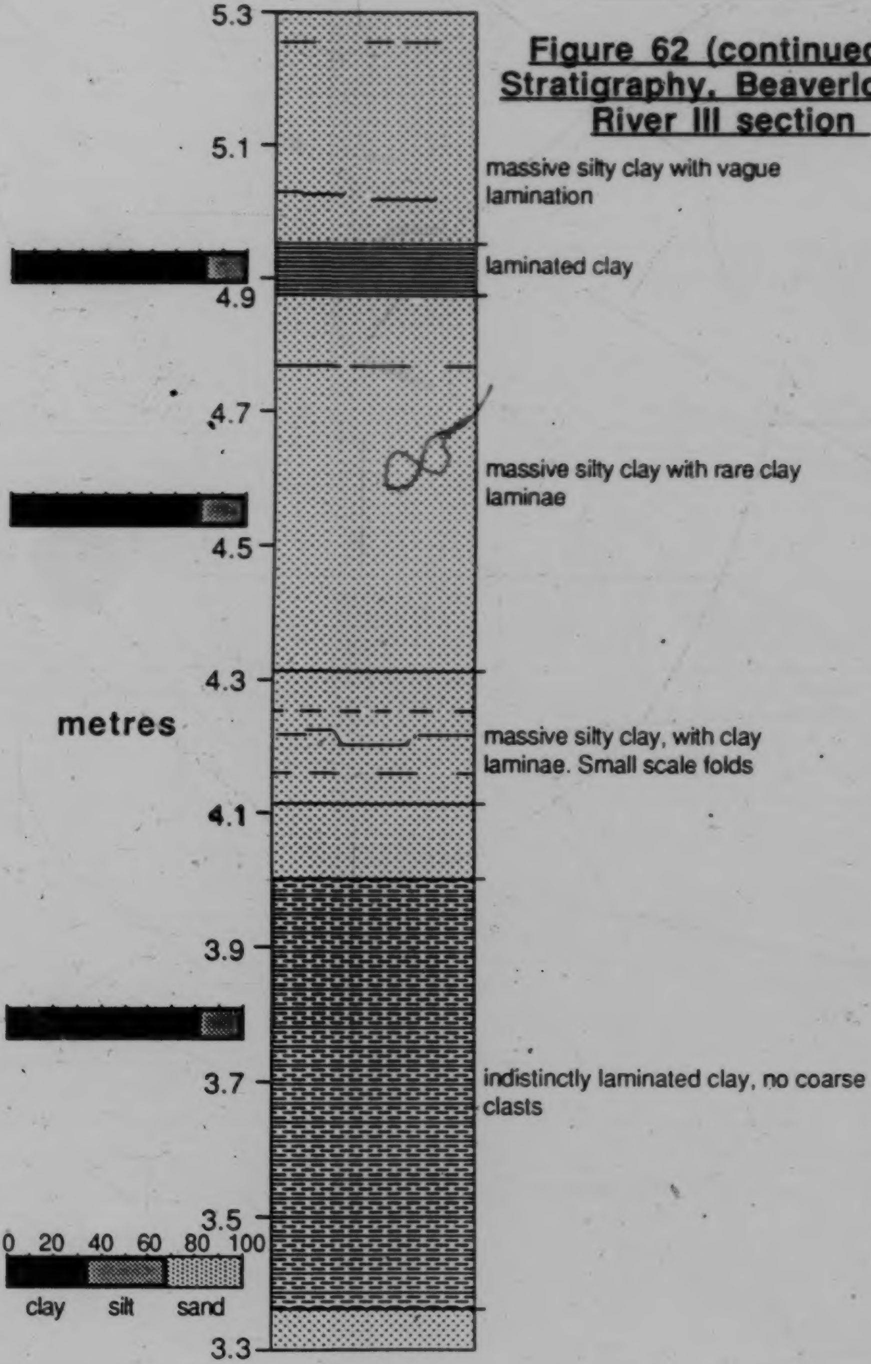
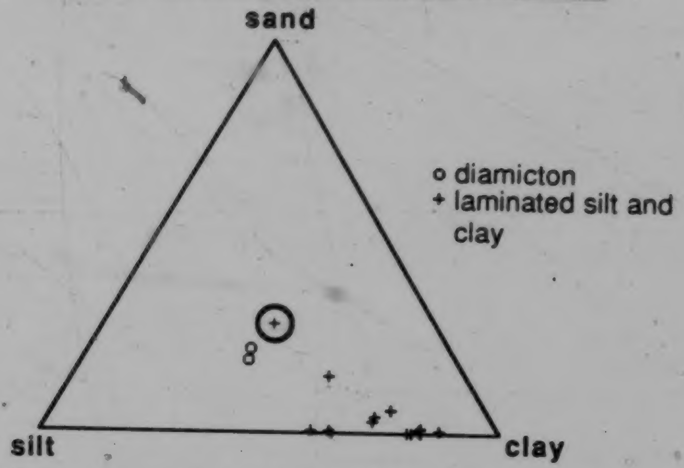

5.3
5.1
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
3.3
metres
massive silty clay with vague lamination
laminated clay
massive silty clay with rare clay laminae
massive silty clay, with clay laminae. Small scale folds
indistinctly laminated clay, no coarse clasts
0 20 40 60 80 100
clay
silt
sand

Figure 62 (continued):- Stratigraphy, Beaverlodge River III section

Figure 63:- Ternary plot, grain size data, Beaverlodge River III section



The single cross showing high sand proportions (circled) is an analysis from a thin diamicton interbedded with laminated clays indicates that flow was from the south, and thus probably directly from ice. If the source of debris flows was remobilisation of till from the valley sides, the direction of flow would be to the south, paralleling local slope. The presence of stratification in the diamictons may be due to the nature of the debris flow, or due to current action on the surface of a stagnant flow. The sharp upper contacts and well defined margins of these diamictons indicates plastic flow (Nardin *et al.* 1979). The prominent normal grading in the sand beds indicates that they likely are the result of proximal turbidity currents (c.f. Walker 1984). This would indicate that the sand beds were deposited close to a source of fluctuating discharge, with a high sediment load. This was probably meltwater from the retreating ice sheet. Sequences resembling this association have been described by Powell (1981), McCabe *et al.* (1984, 1987), and Visser (1983, 1984) and interpreted as showing sub-aqueous ice marginal deposition.

Sediment association 2- description

A sharp undulating contact separates sediment association 1 from a sequence dominated by rhythmically bedded silts and clays, with some diamicton interbeds (Figure 62, Plate 19, Plate 20). The rhythmites consist of normally graded beds and laminae of silt and clay, with no sharp division between the silt and clay component. Each stratum is between 0.8 and 2 cm thick. Coarse clasts up to 10 cm diameter, that deform underlying bedding and are draped by overlying bedding, are common. Within individual beds rounded and angular intraclasts of silt and clay are abundant. Bedrock clasts with diameters less than strata thickness, that do not deform lamination, are common and are concentrated at the base of strata. Each stratum is composed of a series of thin graded laminae, with up to 15 laminae discernable within a single

8

Plate 19:- Beaverlodge River III section, overview. Cheryl Squair for scale.

Plate 20:- Contact between sediment associations 1 and 2, Beaverlodge River III section. Coin for scale.

stratum.

Diamicton beds are thin, generally sand and silt rich, with abundant small clasts and intraclasts. Some beds are discontinuous, pinching out to the north, but others are continuous over at least 5 m horizontally. Generally beds have sharp undulating upper contacts, and sharp horizontal lower contacts. In some cases the upper contact is gradational and the diamicton forms the base of a silt/ clay rhythmite. Diamicton constitutes approximately 15% of the association.

Interpretation

The second sediment association represents a glaciolacustrine ice-proximal environment with considerable ice rafting of material. It is dominated by repeated graded beds, indicating that sediment was being deposited in regular pulses by waning currents. Thus it is likely that periodic turbidity currents from a glacial meltwater source were responsible. The small scale grading within individual beds indicates that each major turbidity flow was composed of a series of minor flows which progressively declined, with traction current sedimentation being eventually replaced by settling from suspension. The common coarse clasts are interpreted as dropstones due to their relationship with the stratification. Intraclasts are predominantly rip-up clasts, although in some cases deformation of stratification indicates that rare diamicton intraclasts were ice-rafted also. Small diameter bedrock clasts were probably in part transported and deposited by the turbidity current, indicating a poorly sorted source of sediment. Such sediments are typical of ice contact, proximal glaciolacustrine environments (Gustavson *et al.* 1975, Eyles and Miall 1984).

The presence of discontinuous diamicton interbeds suggests that debris flow activity from a ice margin to the south of the area was taking place, and the infrequent grading up into silt suggests that transition from cohesive debris flow to high density turbidity current was common. This transition often occurs as sediment gravity flows accelerate (Lowe 1979). The south-north up-slope flow direction suggests that the flows originated from the glacier front.

Sediment association 3- description

This association is dominated by rhythmically bedded silts and clays (Figure 62, Plate 21). Coarse clasts and intraclasts are present but uncommon. Diamicton interbeds are rare and constitute less than 5% of the sediments. Graded silt/ clay strata similar to those of the second association are common. Repeated internal normal grading is common in thicker strata, and generally no sharp division between coarse and fine components of couplets is seen. These strata overall show a thinning upwards trend, although individual strata form exceptions. Sequences of these graded strata are interbedded with beds and laminae of vaguely laminated silt and silty clay, with no apparent grading. Thus a sedimentation cycle can be recognised, with thicknesses of 5 to 20 cm with each "couplet" consisting of a relatively thick strata of silt overlain by a sequence of graded silt/ clay laminae.

Diamictons are silt and sand rich, stratified, and often grade upwards into silt. They have sharp basal contacts. Towards the top of this sequence prominent beds of massive silt are found, and mark the transition to the fourth sediment association.

Interpretation

The smaller scale rhythmic lamination has a similar origin to that seen in the second association. The massive silt beds characteristic of the second larger scale cyclicity are thought to have originated from a non-glacial source. The topographic situation indicates that the sections may have been affected by

Plate 21:- Sediment association 3, Beaverlodge River III section. Note interbedding between laminated silt and clay, and unstratified silt and clay. Knife is 10 cm long.

inflow of meltwater from both a fluvioglacial source (the ice dam impounding the lake), and from a non-glacial source- the Beaverlodge River, with a catchment area to the north and west, where glacial ice may have been absent during the development of the lake. Such non-glacial sources would have high sediment loads resulting from reworking of recently deposited glacially derived material before stabilising vegetation was established, and would be less variable in discharge than inflow from a glacial source. Thus the silt beds of sediment association 3 may result from periods when there was little glacially derived meltwater bringing sediment to the area, and formed through suspension settling of material supplied by the Beaverlodge River. This would probably be most likely to occur in the spring and autumn, when areas not covered by ice would be able to respond to temperature changes more rapidly. During the melt season, such sedimentation would continue, but frequent turbidity currents would mask its effects.

Ice was still close to the area, as shown by the presence of ice-rafted clasts and diamicton beds interpreted as resulting from high density turbidity currents. The poorly sorted nature of the diamicton suggests that its source was also poorly sorted, and likely was glacigenic sediment derived from the ice margin. It is possible that the source of debris flows was slope failure and remobilisation of previously deposited sediment in positions remote from the ice margin.

Sediment association 4- description

The fourth sediment association is characterised by a lack of coarse clasts, and a gradual disappearance of graded rhythmically bedded silts and clays. It is dominated by interbedded massive buff silts and poorly laminated dark grey clays. This is the thickest of the sediment associations, constituting the upper 5 metres of the section.

Interpretation

The last sediment association is interpreted to show the retreat of ice from the vicinity as suggested by the absence of ice rafted material, and the decline in importance of rhythmically bedded sediments derived from turbidity flows. Massive or poorly laminated silt and clay beds constitute the majority of the sequence, and probably result from the input of sediment from the Beaverlodge River entering the lake from the northwest, rather than from glacial meltwater. Interbeds of rhythmites of graded beds and laminae of silt and clay are seen at the base of this association and represent distal turbidity flows from glacial meltwater, probably only reaching the area at the height of the melt season. These disappear higher in the section, suggesting retreat of the ice margin.

Summary- Beaverlodge River III section

The sediments show the effects of retreat of ice from the area, with subaquatic debris flow activity, with some turbidity current action marking the transition from stratigraphic unit C. As retreat continued, turbidity current deposition became dominant, with debris flow activity and ice-rafting significant but minor components. If the sequence represented a steady retreat of an ice margin fronted by a pro-glacial lake, the transition between associations 1 and 2 would be gradational. The sharp contact between associations 1 and 2 suggests that the sediments represent deposition in two separate lakes. Sediment association 1 was deposited in a minor lake, impounded locally. On retreat of the ice front, this lake drained, and lacustrine deposition halted until the time of formation of a larger lake impounded by an ice front further from the section. With further retreat, debris flow activity declined, and sedimentation from a non-glacial source became important. Finally, ice rafting and turbidity current activity declined, and eventually disappeared as sedimentation became dominated by input from the non-glacial Beaverlodge River.

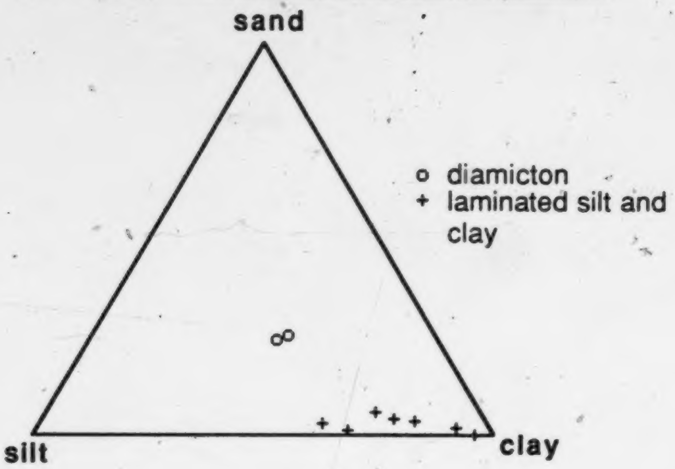
Beaverlodge River I Section

This section is located on the Beaverlodge River, approximately 10 kilometres southeast of the Beaverlodge River III section. The basal part of the section has been considered with stratigraphic units A, and B above (Figures 18 and 64). Discussion is confined to the upper part of the section, where the same broad sequence as the Beaverlodge River III section is seen. Rhythmic graded beds and laminae of silt and clay, with intraclasts and dropstones, are found at the base of the sequence. Higher in the section these rhythmites are interbedded with massive silt beds. Higher yet, the rhythmites disappear, and the sediments consist entirely of massive silt and indistinctly laminated clay, with no coarse clasts. This closely resembles sediment associations 3 and 4 of the Beaverlodge River III section, and is interpreted in the same manner. This indicates that sedimentary environments were consistent over 10 kilometres. There are, however, noticeable differences between the sections:

1. The Beaverlodge River I section shows no evidence of sediments similar to association 1 of the Beaverlodge River III section. Massive diamicton with a moderate northeast oriented fabric (S1 values of 0.56 and 0.66 on two 25 stone measurements) is overlain along a sharp contact by rhythmites of stratigraphic unit D.

2. The basal rhythmites show no diamicton interbeds which characterise sediment association 2 in the Beaverlodge River III section. Some rhythmites contain abundant coarse clasts and intraclasts at their base, which gives them the appearance of diamicton, but the well defined beds with sharp upper and

Figure 64: Ternary plot, grain size results, Beaverlodge River I section



lower contacts seen in the Beaverlodge River III section are not seen.

The differences can be explained by suggesting that the position of the Beaverlodge River I section (10 km southeast of the Beaverlodge River III section) meant that the area was unaffected by deposition in the minor lake that resulted in the deposition of sediment association 1, probably because it was still covered by glacial ice. Thus, following retreat of the ice margin, the section was unaffected by lacustrine deposition until establishment of the second, major, pro-glacial lake. With the formation of this lake, lacustrine deposition commenced, but with the ice margin distal to this section and unable to supply sediment in the form of debris flows.

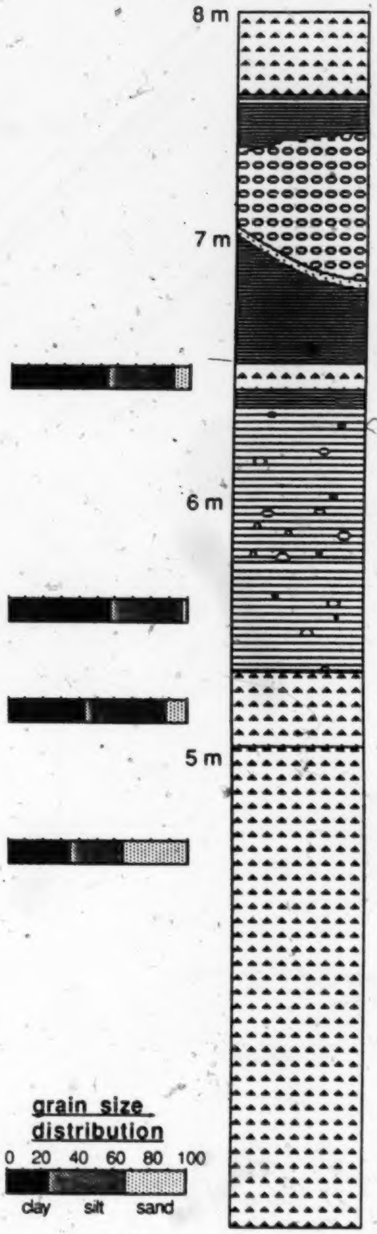
Albright Section

The Albright section is located on the Beaverlodge River, close to the hamlet of Albright and shows 4 m of sediment of stratigraphic unit D overlying a massive diamicton 5 metres thick assigned to stratigraphic unit C. The upper part of the section shows the following sequence (Figure 65):

Unit A-1:- Overlying the basal massive diamicton is 30 cm of massive diamicton with a silt rich matrix, and few coarse clasts. The lower contact is sharp, and the upper contact gradational.

Unit A-2:- This unit consists of 40 cm of massive silt containing coarse clasts. The matrix is moderately sorted, and the proportion of coarse clasts is less than 5%.

Unit A-3:- A gradational contact underlies 30 cm of massive silts, with many well rounded clasts of quartzite with long axes to 10 cm. A fabric from this unit (15 measurements) showed moderately oriented clasts (S1=0.60) with the primary orientation to the southwest. There are a number of near vertical clasts (Figure



A-13: Diamicton, stratified, few coarse clasts, pedogenesis destroys structure in overlying sediments

A-12: Couplets, 0.8-1.3 cm thick, base often diamictic, repeated grading within couplets

A-10, 11: Poorly sorted clast supported gravel, underlain by 2 beds of sand, conformable sharp basal contact. Silt matrix, clasts include limestones, slates, quartzite

A-7 to 9: Numerous fine couplets, thinning upwards to less than 0.1 cm, then thickening to 0.7 cm at top. Stones common. Often deformed and contorted

A-6: Diamicton, few coarse clasts, silty, sharp contacts

A-5: Couplets of silt/ clay, 0.2-0.3 cm thick, stones common (deform and drape laminae), base of some couplets appears diamictic

A-2 to 4: Massive silty clay with stones, common in centre of unit, rare at base and top. Clasts are dominantly well rounded quartzite. Basal contact is gradational.

A-1: Diamicton; massive, few stones, silty

A-0:Diamicton, massive, stony, sandy, columnar joints, clast lithology mainly quartzite, rare red granites, local lithology common, also conglomerate, chert

Figure 65:-Stratigraphic column, Albright section

66).

Unit A-4:- A gradational contact separates units A-3 and A-4. Unit A-4 consists of 30 cm of massive silt with rare stones, and resembles unit A-2.

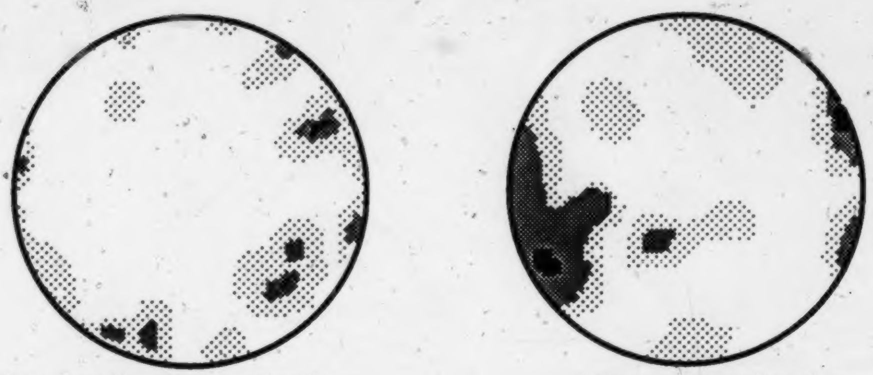
Unit A-5:- This unit consists of 7 cm of rhythmically stratified silt and clay, with each couplet consisting of a graded lamina, with common intraclasts and bedrock clasts which deform lamination. The basal and upper contacts are sharp.

Unit A-6:- This unit consists of a 6 cm thick bed of diamicton, with sharp, undulating contacts. It contained few coarse clasts, and has a silt dominated matrix.

Units A-7 to A-9:- These units consist of a thickness of 25 cm of rhythmically stratified silt and clay, dominated by clay. They show a thinning upward trend in the basal 10 cm, with laminae decreasing in thickness from 0.1-0.2 cm at the base to less than 0.05 cm, and a thickening trend to 0.7 cm over the top 15 cm. Bedrock clasts that deform lamination are common.

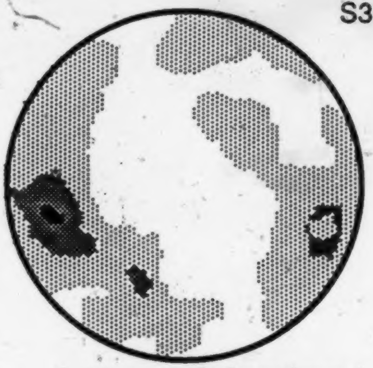
Unit A-10:- Unit 10 consists of two beds of medium and coarse sand, each 3 cm thick. The basal contact is sharp and undulatory, but appears conformable. Both this unit and the upper part of the underlying sequence are deformed, suggesting loading (Plate 22). The beds can be traced over 11 m laterally but appear to pinch out to the north. The sand beds are massive.

Unit A-11:- This unit consists of a lens of poorly sorted clast supported gravel, up to 50 cm thick, and 11 m long (Plate 22). The maximum clast long axis is 40 cm, with the modal size approximately 2-3 cm. The matrix is poorly sorted, but dominantly silt. The clast lithology is varied, but quartzite dominates, with minor angular sandstone and siltstone, and limestone. A clast fabric from the unit is



A-0: basal massive diamicton
S1= 0.55, 13/071, S2= .36,
S3= .09

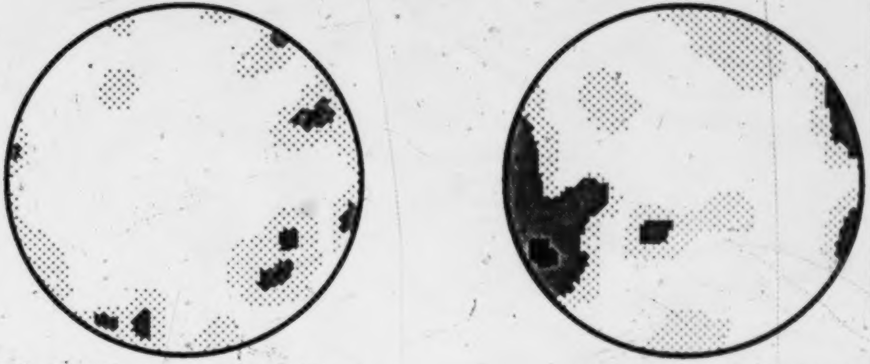
A-2: massive silty clay
S1= 0.60, 19/247, S2= .22 ,
25/148
S3= .18, 58/011



A-11, gravels from lens
S1= 0.58, 17/259 S2= .27 , 10/166
S3= .15 70/046

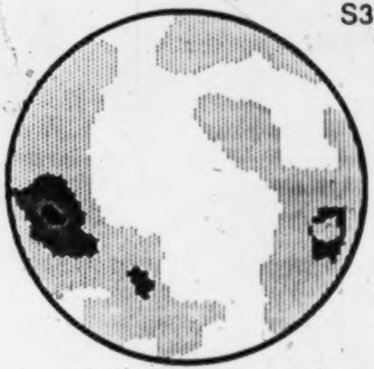
Figure 66:- Fabric diagrams, Albright section

☐ 0
░ 4-8%
▓ 8-16%
■ greater than 16%



A-0: basal massive diamicton
S1= 0.55, 13/071, S2= .36,
S3= .09

A-2: massive silty clay
S1= 0.60, 19/247, S2= .22 ,
25/148
S3= .18, 58/011



A-11, gravels from lens
S1= 0.58, 17/259 S2= .27 , 10/166
S3= .15 70/046

□ 0
▨ 4-8%
▩ 8-16%
■ greater than 16%

Figure 66:- Fabric diagrams, Albright section

Plate 22:- Units A-6 to A-13, Albright section. Pick is 80 cm long.

moderately oriented (S1=0.58), with a relatively high proportion of clasts dipping at high angles.

Units A-12 and A-13:- These units consist of silt/ clay rhythmites, 10-15 cm thick (A-12), overlying unit A-11 with a sharp contact, overlain by a poorly exposed diamicton (A-13), stratified with few coarse clasts. Pedogenesis has destroyed much of the structure in this unit.

Interpretation

Rhythmically bedded silts and clays of units A-5, 7, 8, 9 and 12 are interpreted as in the Beaverlodge III section as being deposited in an ice contact glacial lake by periodic turbidity flows. The internal grading indicates that each major flow was composed of a series of minor flows. Dropstones are common, indicating ice rafting, and intraclasts probably represent rip-up of underlying beds by turbidity flow.

The massive silt/ silt rich diamicton of units A-1 to A-4 may be deposited by a number of processes:

a. By debris flow, analogous to the process postulated for diamictons in the Beaverlodge River III section (c.f. Evenson *et al.* 1977, McCabe *et al.*1984). Such flows may originate either from the ice front, or by remobilisation of previously deposited lake sediment.

b. By continuous rain out from floating ice in combination with suspension settling (c.f. Gibbard 1980, Eyles and Eyles 1983)

c. By rain out following overturn of icebergs carrying debris on their surfaces (c.f. Ovenshine 1970, Thomas and Connell 1985).

Although a categorical distinction between these origins is not possible on the basis of the features seen in the section, it is suggested that these units likely were formed by debris flow following remobilisation of lake sediment as:-

i) the sharp upper and lower contacts seen in some beds and the lack of stratification suggests a debris flow origin rather than rain out;

ii) the silt dominated grain size distribution with few coarse clasts resembles that of the rhythmites within the section;

iii) fabric suggests flow parallel to local slope;

iv) The continuous nature of the beds suggests that rain out by overturn is unlikely.

The gravel/ sand lens of units A-11 is suggested to be a "carapace" structure (Ovenshine 1970), and originated from the overturn of an iceberg carrying sediment on its surface. Evidence for such an origin is:-

i) The conformable sharp upper and lower contacts;

ii) load structures in the underlying sediments;

iii) the weak fabric with a definite vertical component;

iv) The lack of sedimentary structures indicating current flow;

v) The geometry of the unit as a whole.

The degree of sorting of such a structure depends on the depth of water that sediment falls through after overturn, as well as the sorting of the original material. In this case it is suggested that clay size material was held in suspension resulting in a concentration of coarse clasts in a silt matrix.

Overall the sediments indicate deposition in an ice contact glacial lake, with much sediment gravity flow activity in the form of turbidity currents and debris flow, and also a significant ice rafted contribution. In contrast to the Beaverlodge I and III sections, there is no transition to sedimentation unrelated to glacial activity. The Albright section is at an elevation of 730 m, whereas the Beaverlodge sections are at elevations between 690 and 685 m. The pattern of sedimentation suggests that whilst both areas were initially submerged, by the time the sediments seen in the upper part of the Beaverlodge sections were being deposited the lake level lay between 710 and 655 m, and thus the Albright section lay above lake level. This is consistent with observations throughout the area, with thin (1-2 m) sequences of laminated clay and silt with dropstones being found at elevations between 710 and 810 m.

Discussion- sections along the Beaverlodge River

The three sections discussed show some broad similarities, and also some noticeable differences. When viewed as a whole, some conclusions may be drawn regarding the history of deglaciation in the area. The three sections form a transect through the lake basin over a distance of 20 kilometres, with the Albright section at the highest elevation (730 m), and the Beaverlodge River I section the lowest (685 m). These elevations can be compared with those of strandline features observed in the vicinity. The two major series of strandlines observed lie between 840 and 810 m, and 710 and 655 m. Thus all sections lie below the highest series, the Albright section lies above the lower series, and the Beaverlodge River I and III sections lie within the range of lower strandlines.

Only one of the three sections (Beaverlodge River III) shows clear evidence of the proximity of an ice margin. The section is located at a slight constriction in the broad Beaverlodge valley, and it is possible that this enabled ice to maintain a more stable margin during retreat, with ice anchored to the valley walls.

The Beaverlodge I and III sections show a transition from a glacial source of sediment to a non-glacial source, whereas the Albright section is dominated by a glacial source throughout. This indicates that the lake was relatively short lived, and that the lake shore lay somewhere between Albright and the Beaverlodge III section when the upper sediments in the Beaverlodge I and III sections were being deposited. At this time the ice margin was not in the vicinity, as evidence of ice rafting is not seen in the upper parts of the sections.

Thus, it appears that when the lake was impounded at the higher of the two main levels identified in this area, between 810 and 840 m, ice was in the vicinity of Beaverlodge, and supplying sediment to the lake in the form of debris flow and turbidity currents. At this time, extensive lacustrine sedimentation took place over the prairie surface, characterised by turbidity currents depositing rhythmites and ice rafting manifested as dropstones. This phase of the lake development deposited no more than 2-3 m of sediment in the deepest part of the lake and generally 1-2 m of sediment on the prairie surface. The second major series of stable lake levels was between 710 and 655 m. For some of this period, the lake margin lay between Albright and Beaverlodge. The sediments resulting from this phase of lake development are only found at low elevations in the Beaverlodge valley, but form the thickest lake sediments in the area. Supply of sediment to the lake was dominantly from the non-glacial Beaverlodge River flowing from the northwest.

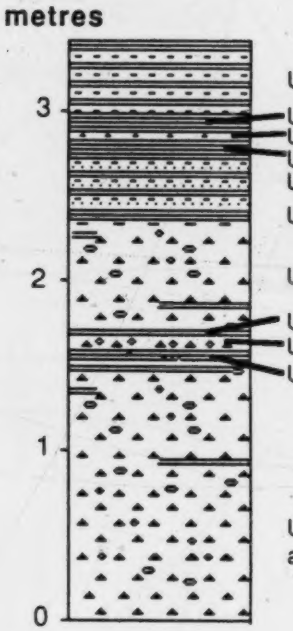
Bear Creek Section

This section is exposed along Bear Creek, northwest of Grande Prairie, at an altitude of approximately 655 m. The section consists nearly 3 m of mainly laminated silt and clay of stratigraphic unit D. Strata are laterally continuous over 30 m of exposure (Figure 67).

Unit B-1- Description

Unit B-1 consists of 1.5 m of diamicton, with a clay/ silt rich matrix, and abundant soft sediment and bedrock clasts. The unit is vaguely stratified, with

Figure 67:- Stratigraphy, Bear Creek section



Unit BC-11:- silt/ clay rhythmites
Unit BC-10:- laminated clay
Unit BC-9:- diamicton normally graded
Unit BC-8:- laminated clay
Unit BC-7:- silt/ clay rhythmites
Unit BC-6:- laminated clay
Unit BC-5:- stratified diamicton with clay laminae
Unit BC-4:- laminated clay
Unit BC-3:- stratified diamicton with clay laminae
Unit BC-2:- laminated clay
Unit BC-1:- diamicton, massive with interstratified silt and clay, many intraclasts

inter-stratification of clay and silt laminae towards the top of the unit. Grain size analysis shows it to be composed of 15% sand, 25% silt, and 60% clay.

Interpretation

The presence of soft sediment clasts of silt and clay, the relative lack of sand, and inter-stratification with laminated silt and clay suggests that unit B-1 was deposited by debris flow in a lacustrine environment. The intraclasts are suggested to be ripped up from silt and clay strata deposited by suspension settling. It is likely that the unit represents a series of minor flows, with intervals of quiet water deposition resulting in clay and silt strata. The source of the sediment for these debris flows is probably resedimented glacigenic diamicton either from local slope failure, or direct from an adjacent ice margin. In either case, the flows have incorporated clay and silt of lacustrine origin, and this results in a finer grain size distribution than glacigenic diamicton of stratigraphic unit C.

Unit B-2- Description and interpretation

Unit B-2 consists of a thin (4 cm) thick bed of laminated clay, with laminae 0.1-0.2 cm thick. Rare coarse clasts deform lamination and were deposited by ice rafting. This unit was probably deposited by suspension settling, with minor turbidity current activity.

Units B-3 to B-6- Description

Unit B-3 consists of 10 cm of diamicton, interstratified with clay laminae, containing many intraclasts. It is overlain by unit B-4, a 1 cm stratum of laminated clays, with individual laminae 0.1-0.2 cm thick. Units B-5 and B-6 show a similar lithology, with unit B-5 consisting of 50 cm of stratified diamicton, with silt and clay laminae, and unit B-6 showing 1 cm of laminated clay. The upper contacts of diamicton beds are gradational, whereas the lower contacts are sharp. Rare coarse bedrock clasts up to 6 cm long axis deform lamination.

Interpretation

These units are interpreted in a similar manner to units B-1 and B-2 above, with diamicton being deposited in a lacustrine environment by debris flow or possibly high density turbidity currents; and laminated clays by suspension settling. The lateral continuity of the diamicton beds suggests that the debris flow depositing them was viscous rather than plastic (Nardin *et al.* 1979). The gradational contacts between diamicton and clay suggest that the upper part of diamicton beds had a major component of suspension settling in their deposition. This might indicate a transition from debris flow to high density turbidity current. Coarse bedrock clasts are dropstones deposited by ice rafting.

Unit B-7- Description

Unit B-7 consists of 30 cm of rhythmically bedded silt and clay, with the base of each couplet consisting of poorly sorted clay, silt and sand 3-8 cm thick, grading upwards into laminated clays, 0.3-1.0 cm thick. A total of 7 such couplets are recognised. The basal part of each contains many soft sediment clasts of clay and silt, and also many bedrock clasts up to 0.5 cm diameter. A sample from the base of one couplet had a grain size distribution of 20% sand, 26% silt, and 54% clay. Coarse clasts that deform lamination are observed throughout the unit.

Interpretation

Each couplet represents the product of a single sediment gravity flow, with the base of the couplet being deposited by either viscous debris flow, or high density turbidity current. The normal grading, and lateral continuity suggest that high density turbidity currents were the primary agent of deposition. Such currents decline in power through time, and leave a cloud of suspended sediment (Nardin *et al.* 1979, Lowe 1979, Walker 1984). Thus the stratum is normally graded, and capped by a sequence of fine grained laminae.

Units B-8 to B-10- Description

Unit B-8 consists of 8 cm of finely laminated clay, with laminae 0.05-0.2 cm thick. This is overlain by unit B-9, a sand rich diamicton, normally graded, with many intraclasts, and some clay lamination. The basal contact is sharp, and the upper contact with unit B-10 gradational. Unit B-10 consists of a further 8 cm of finely laminated clays. Bedrock clasts up to 4 cm long axis are observed, and these deform underlying laminae.

Interpretation

These units resemble units B-2 to B-6 above, and are interpreted in a similar manner, with a combination of sediment gravity flow and suspension settling resulting in the sediments seen.

Unit B-11- Description

This unit resembles unit B-7 in consisting of rhythmically stratified silt and clay. It is 20 cm thick, and contains 14 couplets 0.8- 2 cm thick. Each couplet consists of a poorly sorted silt/ clay base, with many soft sediment and bedrock clasts, grading upwards into laminated clay. Some coarse bedrock clasts deform underlying lamination, whereas the majority of smaller clasts lie parallel to lamination, and are draped by overlying laminae. Above this unit sedimentary structures are destroyed by pedogenesis.

Interpretation

Unit B-11 was probably also deposited by a series of high density turbidity currents, with suspension settling depositing clay in the intervals between currents.

Bear Creek section:- Discussion

This section is located in the southern lake basin at a comparatively low elevation (655 m). It is not located close to a major drainage route, nor in a marked topographic low. As such, the sediments exposed are probably typical of those of much of the southern basin. The sequence seen is best interpreted as ice proximal glaciolacustrine sediment. Proximality is indicated by the common ice rafted clasts, the high proportion of sand in the graded laminae, and the number of debris flows/ high density turbidity currents represented. If the sources of the sediment gravity flows were local slope failure, the number of events is surprisingly large. The local topography is subdued, with no steep slopes which might induce gravitational instability and little gradient to maintain flow over distance. The section also shows a gradual transition upwards from units dominated by diamicton, to those dominated by silt and clay, a sequence that would be more likely to be formed by retreat of an adjacent ice margin, rather than sporadic slope failure.

The section would have been submerged for both phases of stable lake development in the area, with strandline features at high elevation located to the north and west of the section. Thus it would be expected to display a long history of lake sedimentation. The ice proximal sediments, however, probably represent a short time span.

The contrast between the sedimentological history displayed at this section, and those of the Beaverlodge River sections may be explained by examining the differences in topographic setting. The Beaverlodge sections are located in a major valley, and as the ice front retreated, sediment continued to be supplied to the sections by stream flow from the west and northwest. This section is not located in a valley, and sediment supply from a non-glacial source would be minimal. As the ice front retreated to the north and east, meltwater input might induce turbidity currents, but such currents would have to move up-slope to reach this location. Therefore, little sediment was supplied to the section following initial ice retreat.

The majority of lacustrine sediments found in the southern half of the basin are found in a similar topographic setting, and would be expected to show similar sequences. In such settings, sediments were deposited in a brief period when the ice margin was close by, and received little sediment for the remainder of the existence of the lake. The majority of sections in similar settings show thin sequences of rhythmites with occasional diamicton interbeds, and abundant dropstones. Sections showing a more distal style of deposition are found only at low elevations close to drainage channels.

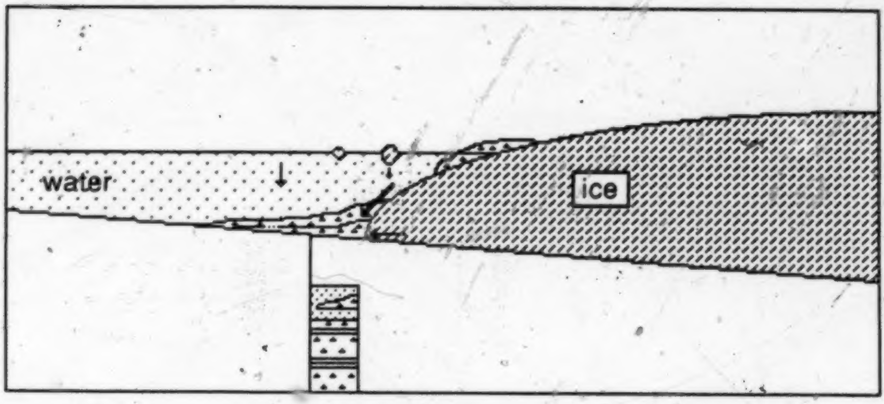
Discussion- Stratigraphic unit D

The above sections illustrate the variation in glaciolacustrine sedimentation seen in the map area. Lacustrine sedimentation in the Grande Prairie area is controlled by the position of the retreating ice margin, and local topography. The lakes formed in retreat were all formed in a similar topographic setting.

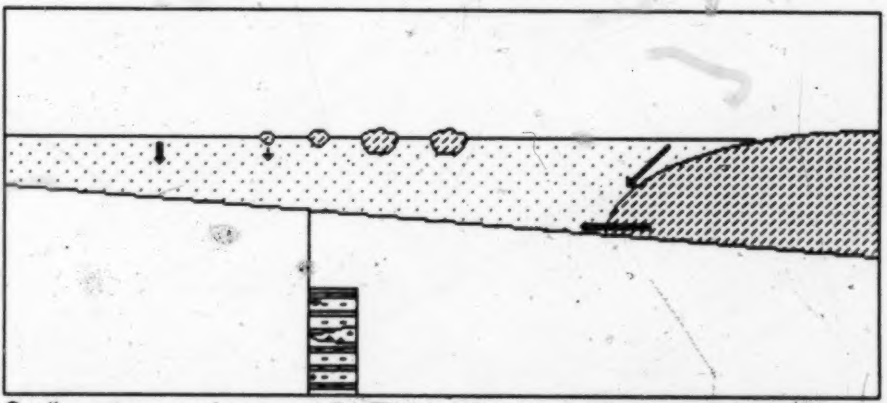
Sedimentary environments

Hypothetical sedimentary environments are presented in Figure 68. Each environment is based on sequences observed in section. Glaciolacustrine sedimentation was dominated by sediment gravity flow. The ice margin was retreating down the regional slope, and thus sediment supplied from the ice margin had to be moved up-slope to reach areas away from the ice margin.

Setting 1 is dominated by the ice margin. The local topographic high formed by the ice itself gives a sufficient gravitational potential to move sediment into

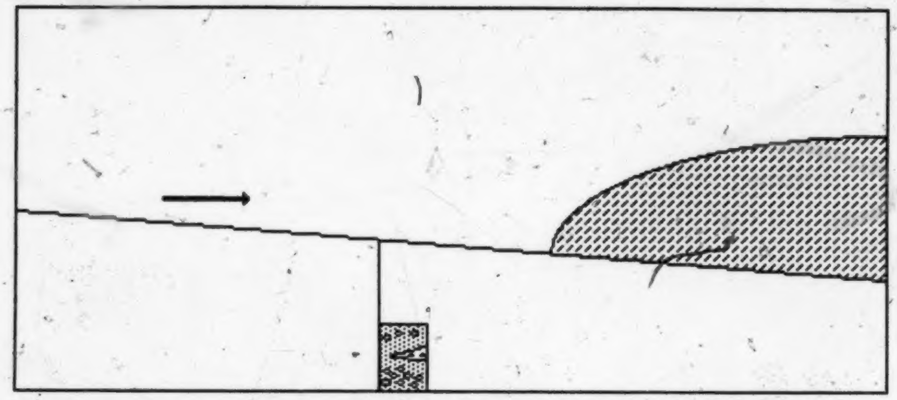


Sedimentary environment 1:- the ice front is close to the section, and is acting as a source for high density turbidity currents and debris flows. Suspension settling and ice rafting also provide sediment to the system, as does meltwater. The sucession produced is dominated by diamicton, interstratified with sorted sediment.

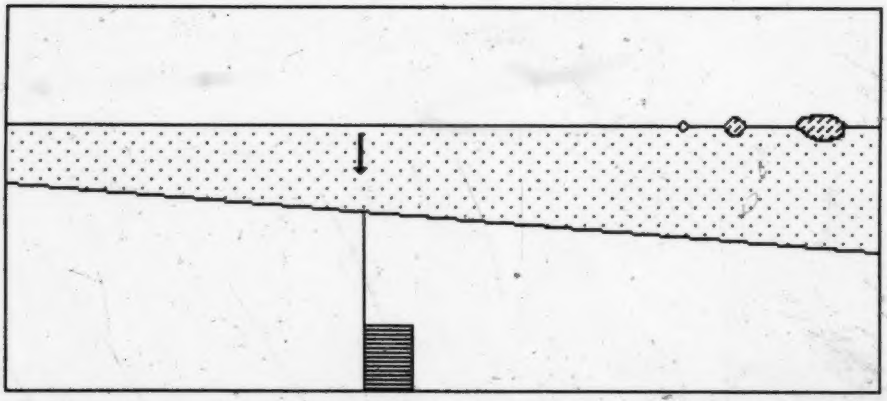


Sedimentary environment 2:- The ice front is further away than in environment 1, but is still a topographic high providing sediment gravity flows to the section. Turbidity currents dominate over debris flow, and suspension settling and ice rafting become more important. Rhythmic stratification with many dropstones dominates over diamicton in the sediments deposited.

Figure 68:- Glaciolacustrine sedimentary environments in the Grande Praiaire area



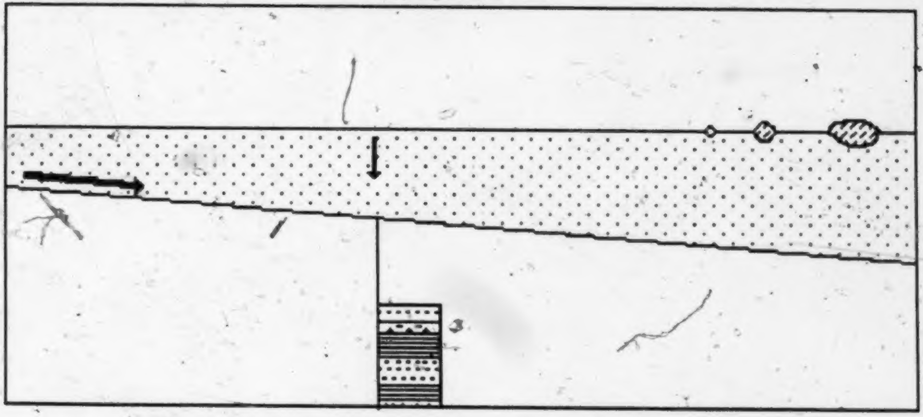
Sedimentary environment 3:- the lake has drained, leaving only fluvial sedimentary input, with possibly sub-aerial debris flow from the ice margin, depending on the distance from the margin to the section



Sedimentary environment 4:- the ice front is some distance from the section, and is not high enough to provide a source of sediment gravity flows. Ice rafting is minimal. The section is positioned away from any inflow to the lake from a non-glacial source, and thus the main input of sediment to the section is suspension settling.

Figure 68 (continued):- Hypothetical glaciolacustrine environments, Grande Prairie Region

Figure 68 (continued):- Hypothetical glaciolacustrine environments, Grande Prairie Region



Sedimentary environment 5:- This setting is similar to environment 4, apart from the input of turbidity currents from a source up slope of the section. These will show a sequence of increasing proximality if the lake level drops. Slope failure may result in deposition of diamicton. The rhythmic nature of the silt and clay deposited depends on the cyclicity of discharge and sediment supply of the inflow stream.

the lake. Sedimentation consists of a combination of diamictons deposited by debris flow and high density turbidity currents; graded beds of silt and clay deposited by turbidity currents; and clay laminae deposited by suspension settling. Ice rafting supplied coarse clasts as dropstones, and rarely more complex deposits as seen at the Albright section. Sediment supply was high, and sedimentation rapid, mainly plastic and viscous debris flows, depositing a sequence dominated by diamicton. The resulting sediments are associated with stratigraphic unit C and mark a transition between units C and D.

Setting 2 is still dominated by the ice margin, which retains its topographic position so as to be the source of sediment gravity flows. Although all the processes interacting in setting 1 are still operating, their relative importance changes. Sedimentation is dominated by turbidity currents generated either from meltwater from the ice front, or from transition from debris flow. These currents produce rhythmites, with the grain size of the sediment depending on proximity to the source of the currents. The base of each rhythmite may be diamicton, sand, silt or clay. Intraclasts ripped up from underlying sediment are common, as are ice rafted coarse clasts. Diamictons, often discontinuous in section, result from debris flows from the ice margin. With retreat of the ice margin, the sediments will show a decrease in grain size of the basal part of rhythmites, a thinning in rhythmite thickness, fewer intraclasts, a decrease in ice rafted clasts, and fewer diamicton interbeds.

Setting 3 is a non-lacustrine environment, where the ice marginal lake has drained, and sedimentation is either by fluvial activity, from streams draining towards the ice, or by sub-aerial debris flow from the ice margin. Most sites in pro-glacial settings would receive little or no sediment in this setting.

Setting 4 is such that the ice margin has retreated so that it no longer maintains a sufficient altitude relative to the section to provide sediment as sediment gravity flows. Such flows would have to move up-slope to reach the section, and their momentum is not adequate, declining in power rapidly on the slope. Thus the only sediment supplied to the section must be from other sources. In this setting, the section is relatively topographically high, remote from any fluvial inflow from directions other than the ice margin. Thus the major process operating is suspension settling. The ice margin provides a minor amount of sediment by ice rafting. The topographic setting would not allow large bergs to move away from the ice front, as the water depth declines away from the margin, resulting in grounding. Smaller bergs and floes carry less sediment, and melt rapidly, and therefore the amount of ice rafting declines away from the margin. Some sediment may reach the section following slope failure at the margins of the lake but such sediment gravity flows are topographically controlled and will preferentially move towards topographic lows. Such lows are usually the site of fluvial input to the lake. Thus very little sediment is deposited in this setting, and suspension settling dominates, with possibly some reworking by wave or wind induced bottom currents.

Setting 5 resembles setting 4 in the position of the ice margin, but differs in that the section is in a topographic low. Such lows form the modern valleys, and re-establishment of streams at the lake margins results in input of sediment at the point of inflow of these streams. Re-established streams would have abundant unconsolidated sediment available for erosion, and would initially have a strong cyclicity of meltwater discharge and sediment supply. Thus, they would enter the lake as turbid underflows, and generate turbidity currents. The deposits of such currents would consist of silt and clay-dominated graded beds, with most coarse sediment deposited close to the point of inflow. Intraclasts may be common, but ice rafted sediment rare to absent. Diamictons may be deposited as a result of slope failure at the lake margins. Such failures would initiate debris flows and turbidity currents, which would flow towards topographic lows. With a drop in lake level, a transition to more proximal sediment is seen, as the source of sediment moves closer to the point of deposition. With retreat of the ice margin, non-glacial fluvial systems will show less discharge and sediment load cyclicity, and may enter the lake by interflow, and overflow, rather than turbid underflow. Thus suspension settling would become the main depositional process. A setting similar to this has been described by Catto (1987a).

Sedimentary Sequences

The sequences of glaciolacustrine sediments seen in the Grande Prairie area can be explained in terms of transitions between the sedimentary environments described above. Common progressions are described below (Figure 69).

1. Steady retreat of the ice margin, and continuous lake existence

A progressive retreat of the ice margin, with no breaks in the existence of the lake, results in a transition from setting 1 through 2 to either 4 or 5 depending on topographic position. Thus a gradual transition is seen from diamicton; to interstratified diamicton and laminated clay and silt; to clay and silt dominated rhythmic sedimentation. With no alternative sedimentary input, this sequence would produce the sediments described above in the Bear Creek section, and is probably typical of sediments in areas away from river valleys throughout the map area. Close to river valleys, a further transition upwards to rhythmites with

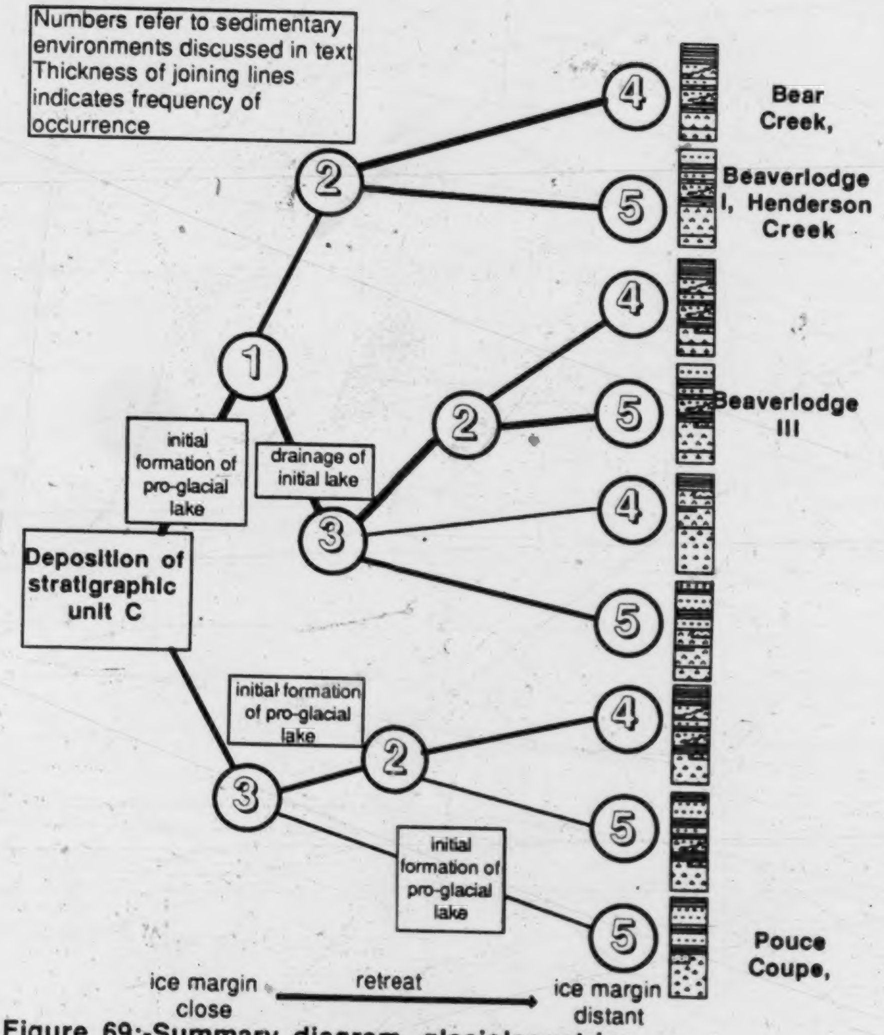

Numbers refer to sedimentary environments discussed in text Thickness of joining lines indicates frequency of occurrence
Deposition of stratigraphic unit C
initial formation of pro-glacial lake
drainage of initial lake
initial formation of pro-glacial lake
initial formation of pro-glacial lake
1
2
3
2
3
2
4
5
4
5
4
5
4
5
5
Bear Creek,
Beaverlodge I, Henderson Creek
Beaverlodge III
Pouce Coupe,
ice margin close
retreat
ice margin distant

Figure 69:-Summary diagram, glaciolacustrine deposition, Grande Prairie area

rare diamicton interbeds, finer, better sorted sediment, and little evidence of ice rafting would be deposited. Such sediment would show evidence of increasing proximality to the source up-section as the ice margin retreated and the lake level dropped. No section clearly shows this sequence in the map area, but the upper part of the Beaverlodge river III section shows the transition from proximal glaciolacustrine sediments to non-glacial sedimentation.

2. Retreat of the ice margin, with discontinuous lake existence

Many sections show evidence of a progression from setting 1 to 3 and then to either 2 or 5. This results in a diamicton dominated basal unit separated by a sharp contact from sediments dominated by rhythmites. In most cases the break in sedimentation resulting from the draining of what were probably minor lakes impounded at the ice front is not marked by deposition. In rare cases sand and gravel beds can be found at the contact (section 86.9 for example). The overlying sequence can show sediments deposited in a sequence from 2 to 5 (as seen the Beaverlodge River I and III sections), or can be deposited solely in setting 5 (Henderson Creek and Pouce Coupe sections). Possible sequences and resulting sediments are summarised in Figure 69.

Summary- Stratigraphic Unit D

In conclusion, stratigraphic unit D was deposited in a series of short-lived pro-glacial lakes by a number of processes, including debris flow, turbidity currents induced by inflow of streams fed by glacial and non-glacial sources, ice rafting and suspension settling. The sedimentary sequence produced is dependent on topographic setting. Low lying areas, which acted as conduits for re-established drainage from the west, show the thickest and most complex sequences, with much of the sediment being derived from these non-glacial sources, and resedimentation of glacigenic and lacustrine sediment. The extent of ice marginal sedimentation, and sediments largely derived from the retreating Laurentide ice is constrained by the regional topographic gradient up away from the ice margin. This results in sediment gravity flows from the margin being restricted to a narrow zone where the local topographic high of the ice front can provide sufficient potential energy to overcome the regional gradient. Potential energy available to drive sediment gravity flows would have been greatest at the deepest point of the lake, where the ice is thickest. Thus sedimentation is again concentrated in topographic lows. Away from the topographic lows, the ice margin is comparatively thin, and the lake was shallow. This resulted in a brief episode of ice marginal sedimentation, followed by little deposition for the rest of the existence of the lake.

This basic sedimentologic setting should apply in many areas in the prairies, where ice dammed lakes were ubiquitous, and ice moved up regional slope. The model has some predictive power, and could be tested in other areas, and by a more extensive examination of sections in the Grande Prairie area.

CHAPTER 7:-STRATIGRAPHY AND SEDIMENTOLOGY - STRATIGRAPHIC UNITS E AND F

Stratigraphic unit E

This stratigraphic unit is identified by its lithology (gravel and sand), its clast composition (containing material derived from the Canadian Shield), its stratigraphic relationships (overlying erosive contacts with bedrock, or stratigraphic units A, C or D), and its terraced geomorphic setting. It is commonly found adjacent to or in major river valleys throughout the area, and constitutes map unit 15 (see Chapter 2 above). The morphology of the terraces has been described in Chapter 2.

Examination of sediments exposed in gravel pits and natural cuts shows the unit to be mainly composed of clast supported gravel, with thickness of up to 35 m. Section 30.6.1 (located south of Grande Prairie, Appendix 1) contains 30 m of moderately to poorly sorted gravel, with well rounded pebbles, cobbles and boulders with a median long axis of 15 cm. Rough horizontal bedding is the dominant sedimentary structure, and clast imbrication is also poorly developed. Clasts are dominantly quartzite, with prominent red and pink granites and gneiss derived from the Canadian Shield, chert, and rare carbonates. Some interbeds of cross bedded sand are rarely exposed. The matrix is poorly sorted fine sand. The sediments resemble the deposits of a proximal braided stream (Miall 1977, Rust and Koster 1984), typical of paraglacial environments. This is a high level terrace of the Wapiti River, and may have formed when water supply to the Wapiti was dominated by the glacial meltwater discharge cycle.

Section 19.7.6. is exposed in a gravel pit, through a low terrace of the Peace River south of Dunvegan (Appendix 1). This section shows a succession from gravels at the base to colluvium at the top. The basal gravels are 30 m thick, moderately to poorly sorted, matrix supported, and roughly horizontally bedded. Planar tabular cross beds are also seen. The largest clasts are 30 to 40 cm long axis, and the modal clast diameter is 4 to 5 cm. The matrix is mainly coarse sand. Clasts are dominantly quartzite, with red and grey granites, limestone, dolomite, chert, and sandstone also present. Interbeds of horizontally stratified and planar tabular cross beds of sand constitute 10% of the unit. Towards the top of the unit the gravel contains angular clasts of sandstone and shale up to 1 m diameter, derived from local bedrock. Also found at this level are rounded clasts of diamicton, up to 60 cm diameter. The diamicton has a clay rich matrix, and coarse clasts are concentrated towards the outside of the clast.

The gravel unit is overlain by 4 m of well sorted medium to coarse sand, dominantly horizontally bedded, with minor trough and planar tabular cross beds. This is overlain by a 1.5 m unit consisting of poorly bedded fine to coarse sands with abundant intraclasts of laminated silt and clay up to 0.5 m diameter. The intraclasts are elongate and angular, and are frequently folded and deformed.

The sequence as a whole represents deposition in a fluvial system, probably braided, in a site subject to much colluvial activity. The basal unit represent gravels deposited in channel bars, with sand deposited on channel abandonment. The sequence probably represents a less proximal style of deposition than that seen in section 30.6.1. Diamicton and bedrock clasts are provided to the system by slope failure of valley sides. The diamicton clasts resemble armoured mud balls, and may have picked up finer clasts when rolling down the valley sides. The uppermost unit shows many clasts derived from lacustrine sediment of stratigraphic unit D, again provided to the fluvial system by slope failure.

Stratigraphic unit E- Discussion

The sequences described above are typical of the stratigraphic unit, although the extent of colluvial sedimentation seen in section 19.7.6. is unusual. It is likely that the upper terraces contain less sand and more coarse gravel than the lower, being deposited in a fluvial system of higher energy, with a greater sediment supply. The lower terraces were probably deposited in a similar setting to the modern rivers. Colluvial activity increases with down cutting of the river systems, and can be seen to be active in the modern rivers. Such colluvial input results in the preservation of anomalously coarse clasts, as well as intraclasts in the fluvial sediments.

Stratigraphic unit F:- Well sorted sand and silt

This unit consists of well sorted sand and silt, overlying sediments of stratigraphic units D and E, and associated with domes and parabolic ridges. It is represented on the map by units 16 and 17 (Figure 7). The geomorphologic associations and well sorted nature of the sediments strongly suggests that the unit was deposited in an aeolian environment. Numerous sections were found through this unit in the south of the map area. These sediments are the subject of a detailed sedimentologic study (Halsey *et al.* 1987, Halsey, 1989) and thus will not be discussed in detail here. One section (30.6.2, location given in Appendix 1) provides some chronologic evidence and so will be briefly discussed below.

Section 30.6.2 is exposed in a gravel pit on a high level terrace of the Wapiti River, overlying the gravels of 30.6.1. Over 20 m of well sorted sand is exposed, consisting dominantly of cross-stratified fine to medium sand. Rare evidence of water saturation is found towards the upper part of the section (Halsey *et al.* 1987). These sediments were deposited as a parabolic dune migrated over the area. There is no evidence of vegetation preserved in the section, and it is thought that the main factor controlling dune morphology and sedimentation was the presence of water (Halsey 1989). The top of the section shows brunisolic soil development, with a brunisolic B horizon 30 cm thick. To the west side of the exposure, the well sorted sands are overlain by horizontally bedded silt, and silty clay, containing gastropods and charcoal fragments. The gastropods are dominantly non-aquatic species (P.T. Bobrowsky, personal communication, Department of Geology, University of Alberta, 1987). This unit was probably deposited in a minor pond which dried up intermittently. Charcoal from 20 cm above the top of the sands was submitted for radiocarbon dating, and yielded a date of 2030±90 B.P. (GSC-4177). This provides a minimum date for dune stabilisation in the area. This particular dune was probably stabilised some time before deposition of the overlying sediments, as shown by the thickness of the underlying soil horizons. Halsey (1989) found organic detritus in silts underlying aeolian sands, at the base of the same section. These organics were radiocarbon dated at 4030±180 B.P. (AECV-627C). Thus the period of sedimentation depositing this dune is defined as being less than 2000 years. Halsey (1989) notes that elsewhere dunes appear to be truncated by terace development, and suggests that two phase of aeolian sedimentation took place in the Grande Prairie area. The first phase took place synchronous with terrace development, shortly after deglaciation, whereas the phase dated at 30.6.2 was later, and possibly represents reactivation of dunes following local fires.

Thus stratigraphic unit F was deposited by aeolian sedimentary processes.

which were active after the formation of the higher terrace levels south of Grande Prairie, and before 2000 B.P.

CHAPTER 8:- GEOLOGICAL HISTORY AND CONCLUSIONS

Introduction

In this final chapter, the data and interpretations provided in earlier chapters will be used to deduce the Quaternary geological history of the area. The history obtained will then be compared to those proposed by other workers for adjacent areas, and the regional implications examined. Lastly the economic aspects of the study will be reviewed, and suggestions made for further study of problems in the Grande Prairie area.

Pre-glacial geological history

The oldest sediments identified in the area are those of stratigraphic unit A, shown to have been deposited in a pre-glacial fluvial system. These sediments have been dated at the Watino and Simonette sections (>51,000 B.P., GSC-4623 HP; 37,010± 2690 B.P., AECV-428C; and dates in Liverman *et al.* 1988, 1989; Table 2) and are thought to be Middle Wisconsinan. Thus, relatively little of the Quaternary is represented by preserved sediments in the Grande Prairie area. The modern drainage pattern with rivers flowing generally to the northeast was probably established following uplift of the Rocky Mountains in the Tertiary. To the south and west of the map area, numerous flat topped hills are seen, and these are frequently capped by coarse quartzite gravels. Such hills are also recognised by Mathews (1978) to the north of the map area. These show a decline in altitude towards the east and north, and probably represent the initial stages of fluvial deposition following uplift of the mountains (Mathews 1978,1980). The age of these gravels is unknown, but they are considered to be Tertiary. Their equivalents are not recognised in the Grande Prairie area, but Saskatoon Hill, to the south of the map area, is of similar morphology. Odynsky and Newton (1950) reported coarse quartzite gravels high in the Saddle Hills, and speculated that they were Tertiary. These features may be related to this initial phase of Cordilleran dominated fluvial sedimentation.

The pattern of pre-glacial drainage established trough down-cutting through the Tertiary peneplain is that of mature, broad valleys with gentle walls, and of moderate gradient (Carlson and Hackbarth 1974). It is likely that these valleys evolved throughout the pre-Late Wisconsinan Quaternary. The sediments areat present exposed at the bottom of modern valleys, which largely parallel the pre-glacial systems. Thus higher level terraces which may exist toward the margins of the pre-glacial valleys were not observed.

The only section where evidence of periglacial activity is seen (in the form of ice-wedge casts) is the Beaverlodge I section. No datable material was recovered from this section, and so the age of these gravels is unknown. Thus it is not possible to ascertain whether the periglacial climate is related to Late Wisconsinan glacial advance, or earlier cold periods. It is likely that much of the pre-Middle Wisconsinan fluvial sediment was flushed out of the pre-glacial valleys by incision of channels in the Early and Middle Wisconsinan. Further exploration of sections of pre-glacial sediments, especially along the modern valley of the Smoky River, may reveal evidence of older fluvial deposition at higher levels, equivalent to the gravels recognised by Tokarsky (1967) to the north of the Grande Prairie area.

Middle Wisconsinan fluvial sediments are found in the deepest part of the pre-glacial valley systems, directly overlying bedrock. They are up to 40 m thick, and, given the range of radiocarbon dates, appear to represent at least 25,000 years of aggradation.

Pollen, plant macrofossils, insects, ostracods, and molluscs from the sediments at Watino suggest a climate similar to the present in the Middle Wisconsinan (Westgate *et al.* 1971, 1972), and this is supported by the abundant wood fragments and lack of periglacial structures observed at the Simonette and Watino sections. Dredge and Thorleifson (1987) presented maximum and minimum reconstructions of the extent of the Middle Wisconsinan Laurentide ice sheet. The maximum reconstruction shows ice extending to 50 km northeast of Watino. This is incompatible with the palaeoenvironmental and sedimentological evidence from the Watino section, or other equivalent sections in the map area. The minimum reconstruction, with ice no closer than 800 km northeast seems more reasonable considering the flora, fauna, and lack of periglacial structures in the sediments of the dated sections at Watino, and on the Simonette River.

Glacial history

Introduction

The glacial history will be sub-divided into three sections, with the history of Laurentide glaciation being discussed first, the record of glaciation from the Rocky Mountains second, and the relationship between Laurentide and Rocky Mountain ice last.

Laurentide glaciation

The history of Laurentide glaciation in the Grande Prairie area can be deduced from the chronologic and lithologic evidence from the Watino and Simonette sections. These sedimentary successions indicate that Laurentide ice did not reach the Grande Prairie area prior to the Late Wisconsinan. The youngest date from Watino is 27,400±850 B.P. (I-4878, Westgate *et al.* 1971; Table 2), from coniferous wood deposited in a fluvial system that contains no

Laurentide derived material in its sediments. Thus the all time Laurentide glacial limit (that marked by the distribution of erratics derived from the Canadian Shield) is the Late Wisconsinan maximum and no previous Laurentide glacial activity is evident

Laurentide erratics are found throughout the map area. They have been reported to the west of the map sheet by Mathews (1978, 1980), and Reimchen and Rutter (1972). In this study several traverses were made west of the study area to attempt to define the limit of Laurentide glaciation. The distribution of erratics is shown on Figure 70. The limit thus defined is based on comparatively little reconnaissance work, and probably represents a minimum. Erratics found below the maximum known elevation of glaciolacustrine deposits (850 m) may be ice rafted rather than emplaced by the Laurentide ice sheet, and are ignored. The approximate boundary thus defined appears to be controlled by altitude, with erratics being found up to an altitude of nearly 950 m. This boundary is well to the west of that presented by Mathews (1980). Mathews' boundary of the limits of Laurentide ice is defined as "where counts of red granite or gneiss drop off abruptly westward to a concentration at which no more than one or two clasts can be located during a careful one minute search" (Mathews 1980, p 4). Mathews (1980) interpreted the drop as representing a zone of coalescence, and implied that to the west of this limit, Laurentide clasts are present, but can be ascribed to reworking of Laurentide provenance material by mountain ice. The chronological evidence from Watino and the Simonette sections indicates that all such events must have occurred in the Late Wisconsinan. Two hypotheses can thus be considered:-

i. The rapid decrease noted by Mathews (1980) (and supported by clast lithology data in this study) is due to dilution of Laurentide diamicton by local

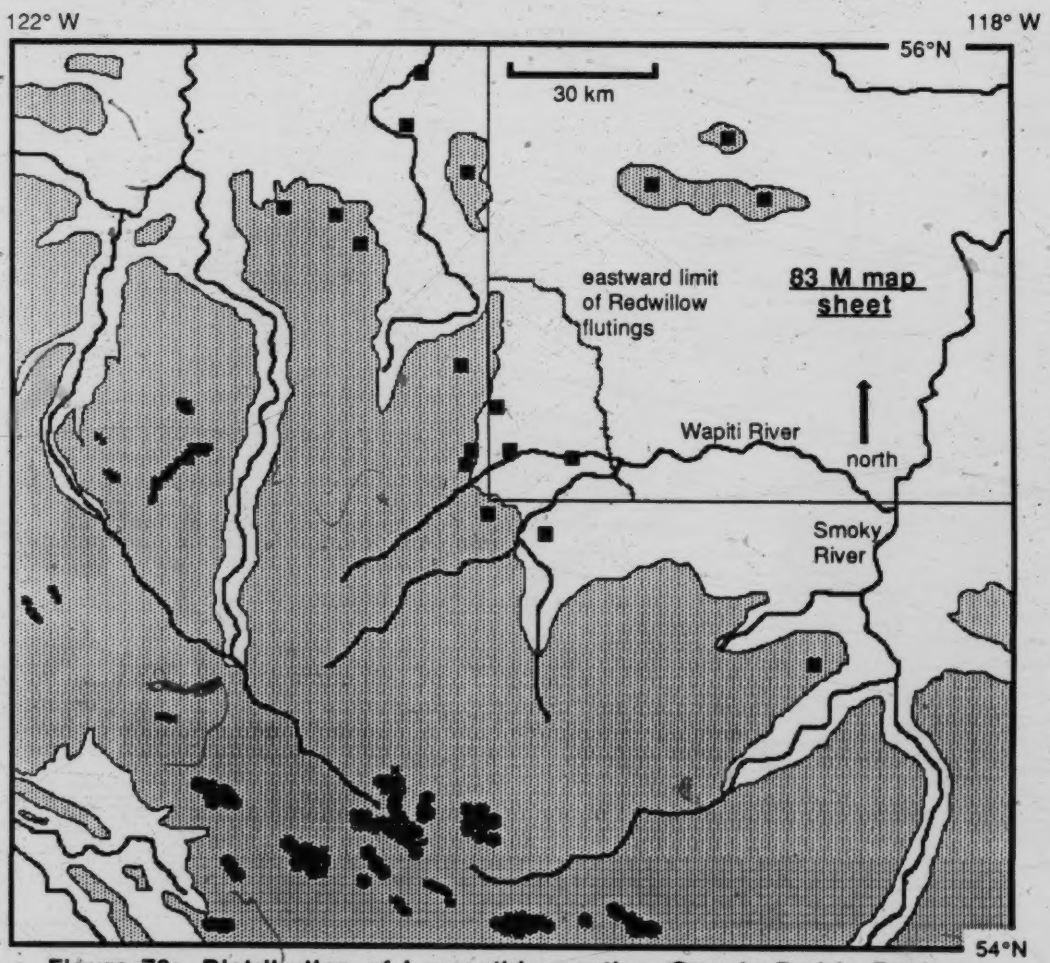

122° W
118° W
56°N
30 km
eastward limit of Redwillow flutings
83 M map sheet
Wapiti River
north
Smoky River
54°N

Figure 70:- Distribution of Laurentide erratics, Grande Prairie Region

Key

▨ area lying between 3000 and 6000 ft (915 and 1830 m)

■ area with altitude greater than 6000 ft (1830 m)

■ location of Laurentide erratics (taken from this study, Reimchen and Rutter 1973, and Mathews 1978) and mountain provenance material. This would occur when the ice eroded and incorporated large quantities of material at its base. This might occur under conditions of compressive flow as the ice moved up-slope into the foothills.

ii. Laurentide ice moved into the foothills early in the Late Wisconsinan, and sediments deposited there were reworked into mountain ice as it moved into the area, later in the Late Wisconsinan.

Under both these hypotheses, Late Wisconsinan Laurentide ice moved into the foothills of the Rocky Mountains with no obstruction from mountain ice. The altitudinal distribution then indicates that the limit of Laurentide glaciation was controlled by topography rather than by the presence of mountain ice. Ice requires gravitational potential to move up-slope, and the magnitude of this is determined by the gradient of the ice surface, the ice thickness at the source of the ice sheet, and the distance from the centre of the ice sheet (Paterson 1969). It is likely that the ice sheet in this area had a low gradient, due to the underlying bedrock being easily deformed (Mathews 1974, Boulton *et al.* 1985, Fisher *et al.* 1985). The ice was thus susceptible to topographic influence. The ice over-topped the Saddle Hills which have a maximum altitude of 940 m, but was unable to move further into the mountain front than the boundary outlined. The altitude of the foothills increases rapidly moving into the mountain front, to the west of the limit.

Flow direction indicators can only be clearly identified above the limit of lacustrine deposition. Those observed in the Saddle Hills suggest a north to south flow, with ice swinging south over the hills from the northwest. Other less well defined lineations observed in the eastern part of the map sheet, are interpreted as showing a northeast to southwest oriented flow. This broadly matches the regional pattern outlined of Mathews (1980). A northwest to southeast trend west of the Saddle Hills can be traced west onto the area mapped by Reimchen (1980) and northwest to the Charlie Lake sheet mapped by Mathews (1978). Eskers and grooves recognised by Henderson (1959) support the northeast to southwest flow in the east of the map area. Thus two clear flow directions are indicated for Laurentide ice.

Ice flow was probably controlled by topography. Mathews (1980) proposed that ice was diverted around the Clear Hills, a plateau attaining an elevation of over 950 m. Flow was enhanced into the topographic low of the Peace River valley and the gap of the Chinchaga Valley. This flow pattern is supported by the evidence from the Grande Prairie area. Mathews (1980) also suggested that this strong topographic control by bed topography indicates that the ice sheet was thin, possibly in the order of 600 m, and the surface slope was low. Mathews (1980) suggested that the curving of flow direction indicators seen to the northeast of the 83 M sheet might also represent topographic control, but could also be due to obstruction by mountain ice. Given the evidence above, it is likely that topography was again the main constraint.

There are few flow direction indicators on the highest parts of the Saddle Hills, and it has been suggested that these may have escaped Late Wisconsinan glaciation (White *et al.* 1979, Mathews 1980). These suggestions have later been retracted (White *et al.* 1985), and the presence of diamicton and Laurentide erratics observed in this study supports the contention that these uplands were over-topped by ice. Ice flow was probably minimal over these areas, with little erosive power, and ice flowed preferentially through the gap in the hills near Demmit to the west of the map sheet, and around the Saddle Hills to the south and east.

Dyke and Prest (1987) suggested that Laurentide ice flowed south or southeast to the Grande Prairie area from a Plains ice divide. This ice divide was oriented roughly east-west, and situated in the area of Great Slave Lake throughout the Late Wisconsinan. This divide is an alternative to the Caribou dome hypothesized by Dyke *et al.* 1982. Neither of these suggestions canbe reconciled with the many examples of Athabasca quartzite found in Laurentide provenance diamicton in the Grande Prairie area. For this material to be incorporated in Late Wisconsinan ice, and transported to the area, ice must have flowed dominantly in a southwesterly direction (Figure 71). The dome suggested by Dyke *et al.* (1982), and the analogous divide of Dyke and Prest (1987), have been postulated on theoretical grounds, rather than field evidence. The field based interpretation of Mathews (1980) is more reasonable given the provenance of clasts in Late Wisconsinan Laurentide diamicton. This reconstruction shows flow dominantly from the northeast, with strong topographic control resulting in the ice flow pattern seen in the Grande Prairie area.

The above evidence suggests a thin ice sheet of low gradient at the time of formation of the features used to infer ice flow direction. Given the regional topography, it is likely that pro-glacial lakes were commonly found at the margin of the ice. The size of such lakes would be dependent on local topography, and the geometry of the ice margin. Evidence for lakes formed in advance was largely destroyed by subsequent overriding by ice, although sedimentological evidence for such lakes is seen (see Chapter 3 and 4).

Pre-glacial fluvial sedimentation continued until at least 27,400 B.P. (Westgate *et al.* 1971, 1972). Laurentide glaciation covered the area at some

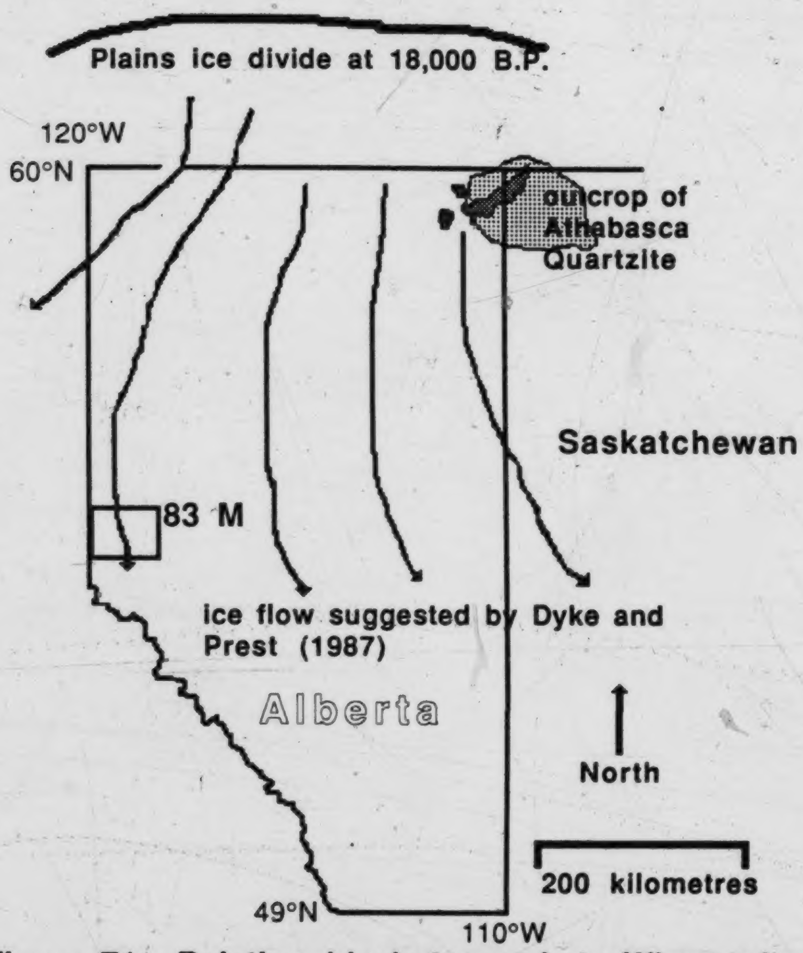

Plains ice divide at 18,000 B.P.
120°W
60°N
outcrop of Athabasca Quartzite
Saskatchewan
83 M
ice flow suggested by Dyke and Prest (1987)
Alberta
North
200 kilometres
49°N
110°W

Figure 71:- Relationship between Late Wisconsinan Ice flow and outcrop of Athabasca Quartzite

The ice flow directions plotted are those of Dyke and Prest (1987), as is the position of the Plains ice divide. The diagram is sketched from their 18,000 B.P. reconstruction, but the suggested position of the ice divide and orientation of flow do not change substantially through deglaciation time following this. The Late Wisconsinan maximum is suggested to have been attained at around 18,000 B.P (Dyke and Prest 1987), but this is no more than a guess in Alberta, where the youngest sub-till dates found are in the order of 23,000 B.P. (Jackson and Pawson 1984).

Rocky Mountain Glaciation

Till or other sediments that were definitively deposited by glaciation originating from the Rocky Mountains were not recognised in the field area. The strongest evidence for the passage of eastward-flowing ice is the presence of a fluting field in the southwest of the map area, fanning out from the Redwillow Valley. These flutes indicate ice flow in directions ranging from due east in the southwest of the map area, and almost due north in the west. The fluting pattern is apparent west of the Grande Prairie map sheet (Reimchen 1980), and appears to originate from the area of the gap cut by the Redwillow River in the mountain front. Mathews (1980) discussed this pattern, noted the discordance between the flutes and southerly ice flow indicators attributed to Laurentide ice, and suggested that the fan morphology is indicative of flow of montane ice unobstructed by Laurentide ice. He suggested that the Redwillow Gap acted as a major outlet for ice from the Cordilleran ice cap. The flutes are draped by lacustrine sediment of stratigraphic unit D, but can be traced in the form of surface lineations as far east as Hythe and Beaverlodge, and north to the base of the Saddle Hills. This extends east of the boundary between mountain and Laurentide glaciation suggested by Mathews (1980), and well east of the Laurentide limit defined here. Mathews (1980) suggested that this fluting pattern truncates an older Laurentide lineation. This is not apparent in the Grande Prairie area, and Reimchen (1980) did not indicate a truncation.

Sediments related to these flutes are not recognised in section, although several good sections are exposed within the region covered by the fluting pattern (including the Beaverlodge I and III sections discussed above). The age of the flutes is unknown. Mathews (1980) suggested that they post-date the Laurentide advance in the area.

Relationship between mountain and Laurentide ice

It has been established above that there has been a single advance of Laurentide ice, which covered most of the 83 M map sheet, and this advance took place in the Late Wisconsinan. Thus all erratic clasts of Laurentide provenance were deposited by this advance, and the limit of Laurentide glaciation is west of the previously defined Late Wisconsinan boundary, at an altitude of approximately 950 m, in the foothills of the Rocky Mountains. There is evidence for at least one major advance of ice from the Rocky Mountains, which has left an extensive fluting field in the southwestern part of the map area. The shape of the fluting field suggests that advance was unobstructed by Laurentide ice. Thus the maximum advances of both Laurentide and mountain ice were constrained by topography, not coalescence of the ice sheets, and, considering the area covered by both ice masses, the maximum advances could not have been synchronous.

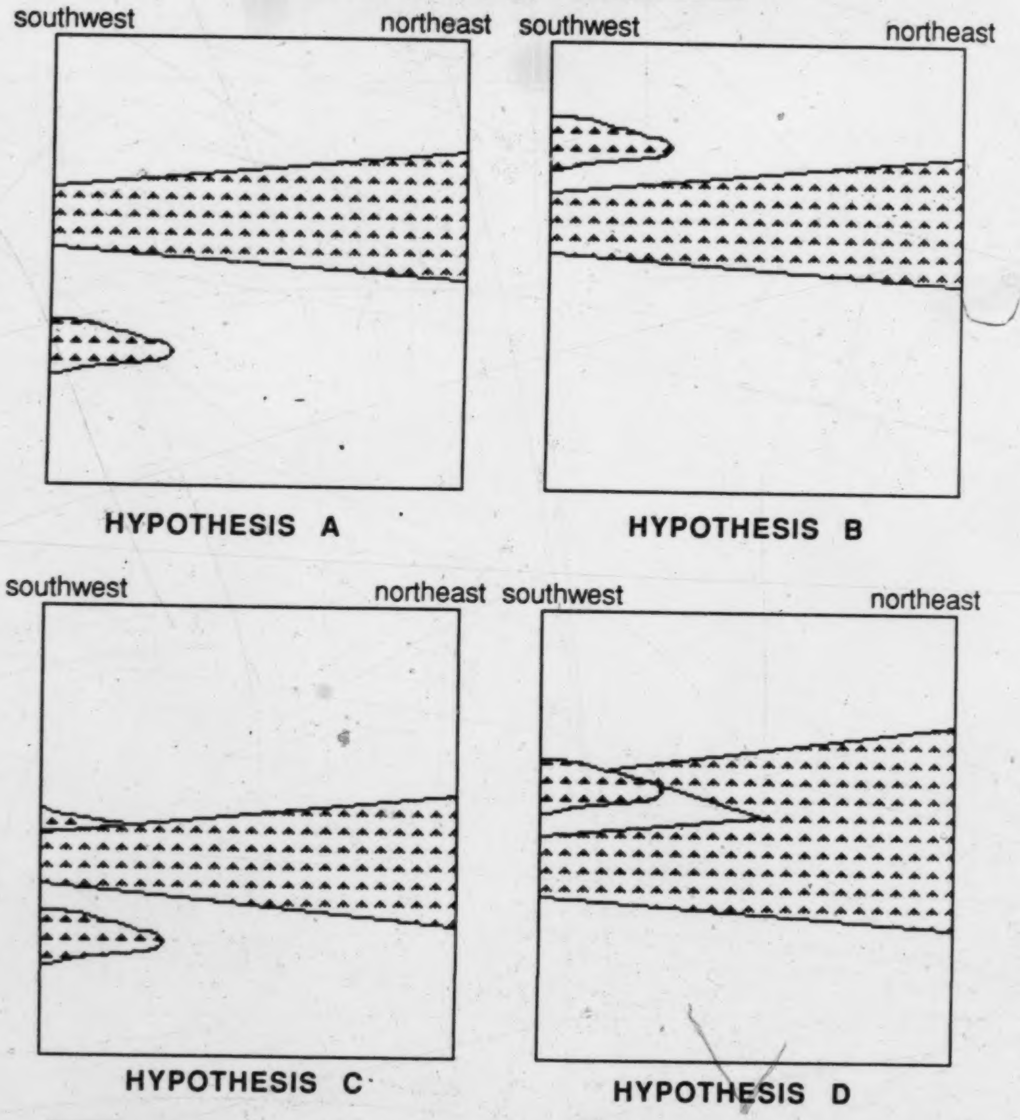
Given the evidence for an unobstructed advance of both ice masses, four hypotheses can be considered for the relationship between them (Figure 72):-

A. Advance and retreat of ice from the Rocky Mountains preceded the advance of Late Wisconsinan Laurentide ice.

B. Laurentide ice advanced and retreated prior to the advance of mountain ice that formed the fluting pattern.

C. Advance of ice from the Rocky Mountains preceded the advance of Late

Figure 72:- Hypotheses concerning the relationship of Laurentide and mountain ice in the Grande Prairie map sheet


southwest
northeast
HYPOTHESIS A
southwest
northeast
HYPOTHESIS B
southwest
northeast
HYPOTHESIS C
southwest
northeast
HYPOTHESIS D

▨ mountain ice

▨ Laurentide ice

Diagrams show time-space relationships of Laurentide and mountain ice in the Grande Prairie map sheet. Vertical axis represents time, but only in a relative sense. See text for explanation.

Wisconsinan Laurentide ice, and formed the fluting field. Subsequent to Laurentide advance to the maximum limit, and retreat to the east, mountain ice re-advanced, and coalesced with Laurentide ice.

D. Laurentide ice advanced and retreated prior to the advance of mountain ice that formed the fluting field, but a re-advance of Laurentide ice resulted in coalescence of the ice masses.

In assessing the validity of these hypotheses, the following lines of evidence must be considered:-

1. The distribution of Shield erratics;
2. The drop in proportion of Shield clasts observed in the southwest of the map area;
3. Common Shield erratics on the surface of the flutes;
4. Draping of flutes by lacustrine sediment deposited in pro-glacial lakes dammed by Laurentide ice;
5. The absence in the map area of diamicton of distinctive mountain provenance;
6. The apparent cutting of flutes by outwash channels carrying meltwater of the Laurentide ice sheet in the area of Kamisak Lake (map unit 14);
7. The absence of stratigraphic sections indicating anything other than a single major Laurentide advance.

Mathews (1980) suggested that the sharp drop in proportion of Shield clasts noted in the southwest of the map sheet is due to coalescence of Laurentide ice and ice from the Rocky Mountains in the Late Wisconsinan. Shield clasts found west of this boundary must have been originally deposited in the Late Wisconsinan by Laurentide ice. Reworking of Laurentide provenance diamicton by mountain ice would explain this drop. Thus the surface diamicton to the west of this boundary would be deposited by mountain ice.

If the diamicton found in the southwest of the map area was deposited by mountain ice reworking Laurentide material, the clast orientations measured in sections should match the fluting orientation. Figure 73 maps the flute orientation, and plots the principal modes and fabric strength from sections in the area. This diagram shows that there are fabrics which appear to align with flute orientation (the upper two fabrics at the Beaverlodge II section, and the fabric from 26.6.5), whereas other sites have clast fabrics which show no relation to flute orientation (the Beaverlodge I section, 86.19, 24.6.3 and 86.20). The diamictons at the Beaverlodge II section are interpreted as being in part resedimented, with fabric controlled by local slope (see Chapter 5, stratigraphic unit C). Thus fabric in sections in this area suggests that sediment was not deposited at the base of northeasterly flowing ice, and is unrelated to fluting formation. Although inconclusive, this suggests that hypothesis D above (which suggests the maximum advance of mountain ice and formation of the fluting pattern followed the passage of Laurentide ice) is unlikely. Hypothesis C, which postulates a readvance of mountain ice following Laurentide retreat, would suggest advance into pro-glacial lakes, and thus flute formation or deposition of basal till with well-oriented fabrics may not have taken place.

The surface sediment draping the flutes, and covering most of the southwest part of the map area is lacustrine, deposited in pro-glacial lakes dammed by the Laurentide ice sheet. If coalescence of the two ice masses took place (hypotheses C and D), then mountain ice must have been close to, or abutting the western margin of these lakes. Under hypothesis B above, it is impossible to explain draping of the flutes by lake sediment. The arguments presented in

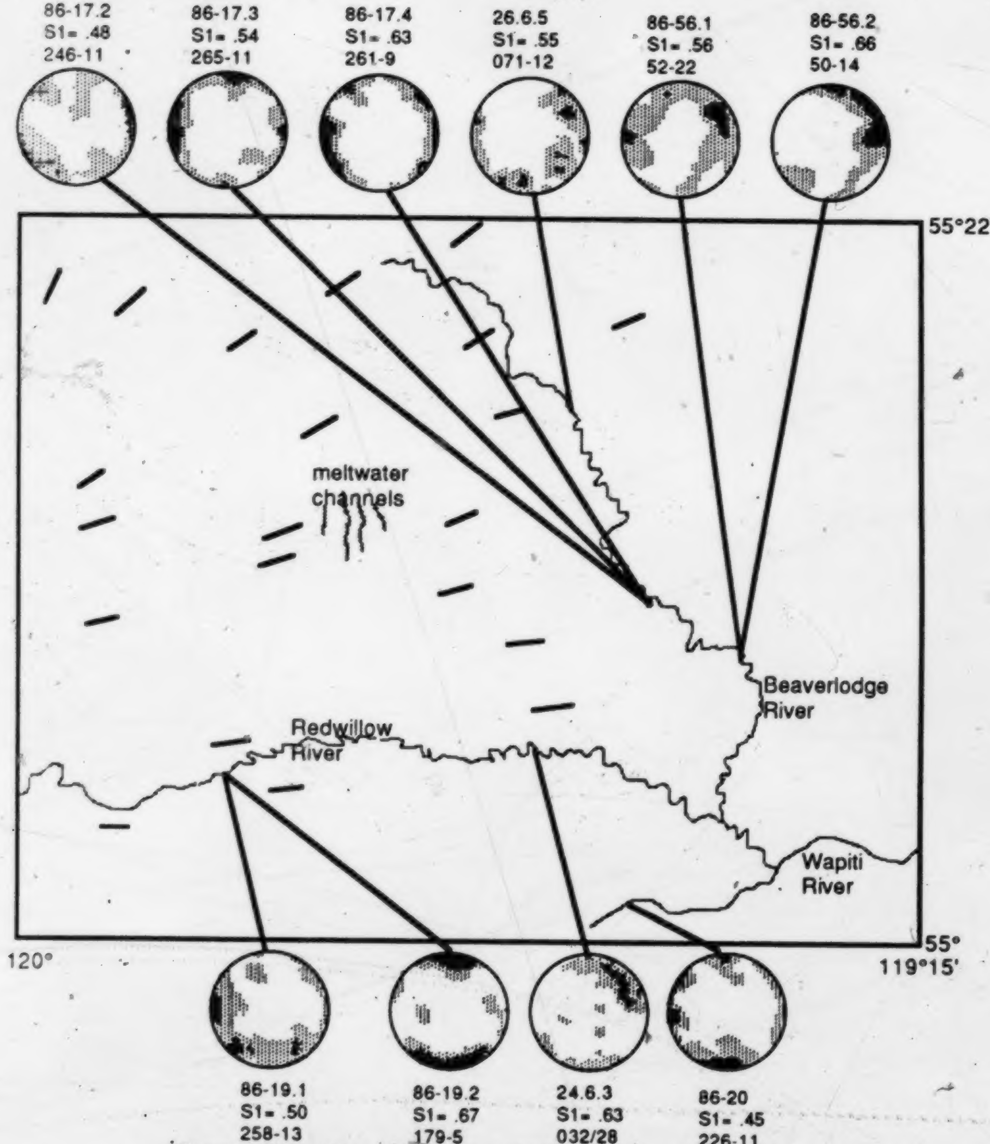

86-17.2
S1= .48
246-11
86-17.3
S1= .54
265-11
86-17.4
S1= .63
261-9
26.6.5
S1= .55
071-12
86-56.1
S1= .56
52-22
86-56.2
S1= .66
50-14
55°22'
meltwater
channels
Beaverlodge
River
Redwillow
River
Wapiti
River
55°
120°
119°15'
86-19.1
S1= .50
258-13
86-19.2
S1= .67
179-5
24.6.3
S1= .63
032/28
86-20
S1= .45
226-11

Figure 73:- Map of flute orientations and fabric diagrams for southwest corner of 83M sheet

Fabric contours are at 4% intervals. Lines represent flute orientations

Chapter 6 suggest that the westerly source of water and sediment was of a non-glacial fluvial regime. Retreating mountain ice should be a major source of meltwater and sediment to eastward flowing streams and rivers. No major areas of glaciofluvial or deltaic sediment were located on the margins of pro-glacial lakes in the southwest of the map area. Interpretation of sedimentological evidence suggests that the lake was comparatively short lived. For the advance and retreat of mountain ice to have taken place during the existence of the pro-glacial lake, both must have to have been rapid. Thus it is unlikely that mountain ice abutted the western margin of the lake.

No clear evidence of re-advance of Laurentide ice was found in the area, with stratigraphic sections suggesting a single advance. Thus coalescence of the two ice sheets is considered to be unlikely.

The last lines of evidence to be discussed are the poorly defined cross cutting relationships seen in the Kamisak Lake area. The surface sediment in this area consists mainly of gravel, thought to be derived as outwash from Laurentide ice (see Chapter 2, map unit 14). A series of north-south oriented channels are interpreted as meltwater fed channels, draining ice lying to the north of the area. The area is at present a topographic high, bounded by valleys to north and south, and thus, to feed meltwater to the area, ice must have been in the direct vicinity, and to form a relative topographic high. Although the relationship is not clear, it appears that these meltwater channels truncate the fluting clearly visible in the area, suggesting that Laurentide ice retreated after the formation of the fluting field.

The formation of the fluting field by mountain ice thus probably occurred before the advance of Laurentide ice in the area, and the sequence of events suggested by hypothesis A is considered most likely.

The preservation of the fluting field must thus be explained as it must have been over-ridden by Laurentide ice. The thin and gently sloping Laurentide ice sheet might have little erosive capability at its margins, and thus would have had little effect on the underlying topography. The ice sheet would be moving up-slope, however, and be in a state of compressive flow, with decreasing forward velocity. Such flow conditions are thought to enhance basal erosion (Paterson 1969), with ice flow up away from the base. It is possible that some erosion has taken place, but the fluting morphology has been accentuated by subsequent development of drainage. The flutings are oriented parallel to the local slope, and thus minor streams have developed between flute crests resulting in increased relief. Thus it is possible that the surface material is a drape of Laurentide provenance diamicton, deposited by melting of a thin, weak ice sheet, and that the underlying flutes are composed of diamicton containing no Laurentide provenance material.

Under hypothesis A, the drop of in proportion of Shield clasts must also be explained. As suggested above, the drop might be caused by dilution of Laurentide provenance material by incorporation of large amounts of local bedrock, and re-worked mountain diamicton. This suggests enhanced erosion at the margins of the ice sheet, and is in contradiction to the arguments above.

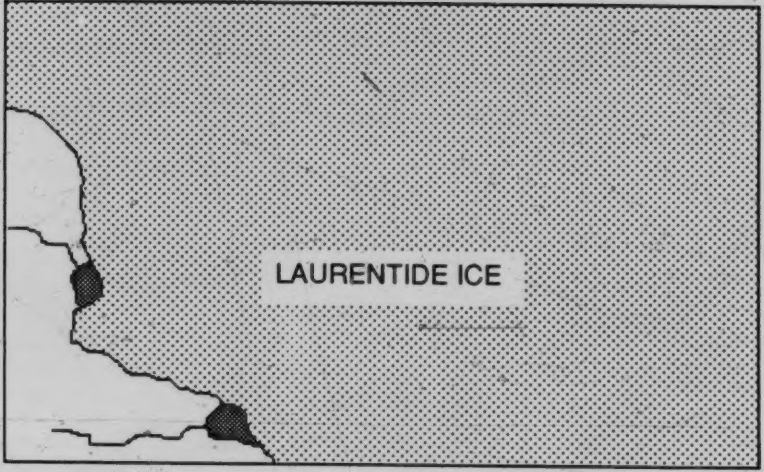
Thus none of the suggested sequences of events are completely satisfactory. The most likely hypothesis suggests that ice from the Rocky Mountains advanced into the area either before the Late Wisconsinan or early in the Late Wisconsinan. There is no evidence of coalescence between mountain and Laurentide ice either in the form of divergence of ice flow indicators or preserved sediments. Thus it is thought that mountain ice had retreated by the time Laurentide ice reached the southwest of the map area during the Late Wisconsinan. An alternative sequence of events, that would have mountain ice advancing shortly after the retreat of Laurentide ice, cannot be completely ruled out but is considered unlikely. Thus, it is concluded that in this area an ice-free zone existed between Laurentide and mountain ice throughout the pre-Late Wisconsinan Quaternary, and probably also in the Late Wisconsinan.

Deglacial History

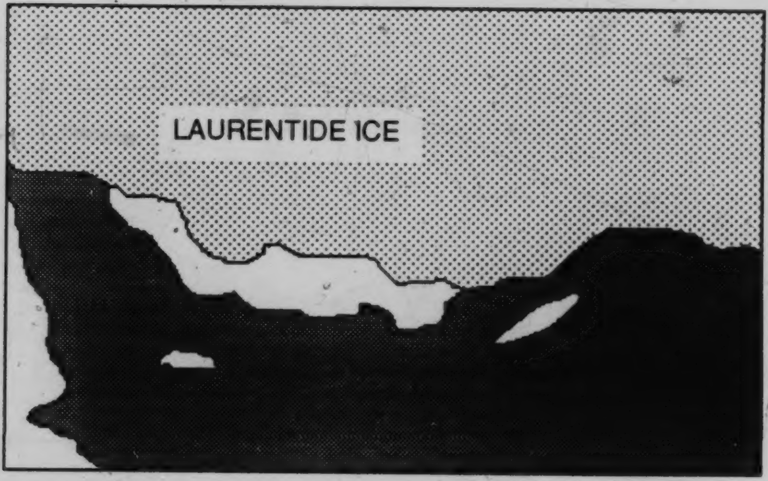
Retreat of mountain ice left little record in the Grande Prairie area. Evidence of deglaciation is dominated by the development of pro-glacial lakes dammed by the retreating Laurentide ice sheet. Four phases of lake development are recognised in the area (Figure 74). The first consists of minor lakes, probably of short lifespan, with sediments deposited directly from the ice margin. These lakes were formed early in the retreat, in positions where local topography allowed their development. One such lake was probably located in the Beaverlodge Valley (see discussion of Beaverlodge I and III sections in Chapter 6 above).

The second stage is marked by strandlines lying between 840 and 810 m, and affected only the south of the area. The position of the ice dam can be determined by examining the distribution of strandline features. It seems likely that the dam was located to the east of the Saddle Hills, possibly in the Bad Heart area. In some areas, the minor lakes of stage one drained prior to the establishment of these lakes, but often the transition between the two lake stages was uninterrupted. The numerous poorly developed strandlines observed suggest that the lake level was not stable for any substantial period of

Figure 74:- Glacial lake formation during deglaciation

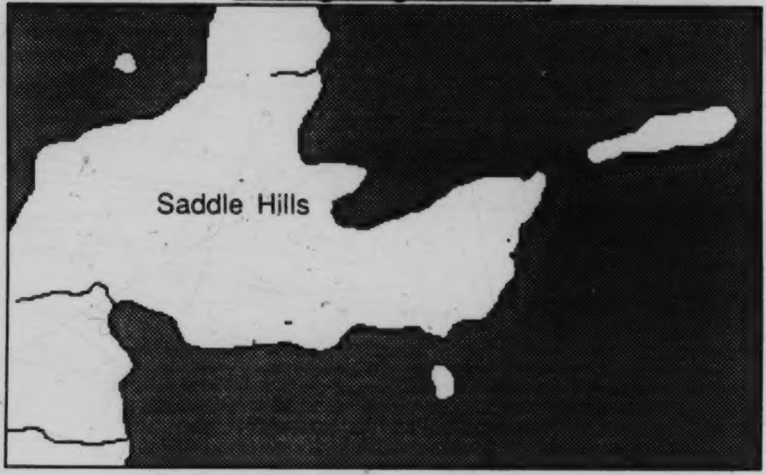

LAURENTIDE ICE

Stage 1:- Minor lakes, probably short lived, and found in any locations where topography allows their development.


LAURENTIDE ICE

Stage 2:- marked by strandlines between 840 and 810 m

Figure 74 (continued):- Glacial lake formation during deglaciation



Stage 3:- marked by strandlines between 710 and 655 m.

Stage 4:- lake developed at low elevations along the Peace River valley

time. The sediments preserved in the lake are interpreted as showing a brief period of existence, in the order of 100 years or less.

The third stage is marked by strandlines and minor deltas between 710 and 655 m, and consists of lake development both south and north of the Saddle Hills. The absence of strandlines between 810 and 710 m suggests a rapid drop in lake level, possibly related to the opening of a new outlet. In the south of the map area, the transition between stages two and three is marked in the deposited sediments by an increase in sediment input from non-glacial sources to the west. The ice dam at this stage was located out of the map area to the northeast.

The fourth stage is marked by coarser grained lacustrine sediment at low elevations along the Peace Valley. Strandline features are not associated with these sediments, and they represent deposition in a pro-delta position in a minor arm of a pro-glacial lake oriented along the Peace River valley.

Despite the probable re-establishment of the three major rivers flowing through the map area (Peace, Wapiti and Smoky), no major deltaic features are associated with these lakes. Although the modern rivers have down-cut some considerable distance, the broad valleys in which they are located are all of comparatively low elevation, and the points of inflow of these rivers to the pro-glacial lakes was out of the map area. Thus deltaic deposits should be found on the margins of the Peace River valley at elevations close to 825 m and 700 m upstream of the Grande Prairie area to the northwest, and similar deposits in the Smoky River valley in the Wapiti map sheet to the south. It is possible that the highest terraces of the Wapiti south of Beaverlodge represent an outwash plain draining into the third stage of lake development outlined above, as the elevations are comparable.

The control on chronology of deglaciation and lake formation is poor, and the best information is that of surface dates. White *et al.* 1985 estimate deglaciation to have taken place over the Saddle Hills at around 12,000 B.P., an estimate based on the degree of contamination of a sample of bulk organics dated at >30,000 B.P. (WAT 361), and an 11,700±260 B.P. date on wood preserved in lake sediments (SFU-223). These dates were obtained from cores of Boone Lake, on the crest of the Saddle Hills, overlying basal sediments thought to reflect the presence of ice adjacent to the lake. St.Onge (1972a) presents dates on molluscs from lacustrine sediments thought to be associated with the lower of the two major lake levels (stage three above), and these range from 13,580-12,190 B.P. (Table 2). As discussed above, at this time the area north of the Saddle Hills was free of ice, and thus if ice was in the vicinity of Boone Lake at 12,000 B.P., it represents an isolated remnant, not associated with the retreat of the ice sheet margin. Reimchen and Rutter (1972) report a date of 16,300±180 B.P. (GSC-1548) for gastropods recovered from a silt mound in lake sediments to the west of the 83M sheet. However, this date was reported erroneously without appropriate correction being made, and the corrected age is 9960±170 B.P. (Mathews 1978). Many other surface dates are in the range 13,500-10,000 B.P., and thus it is suggested that the major stages of lake development took place sometime prior to this date, and were closely associated with the retreat of Laurentide ice. Sedimentological evidence suggests that none of these lake phases were of great duration and that ice retreat was rapid. The development of intermediate level terraces dated by Churcher (1984) and Burns (1986) at close to 10,000 B.P. indicates that ice had retreated from the area at this time, and that pro-glacial lakes were absent from the area.

Post-glacial history

Following drainage of the glacial lakes in the area, a number of processes became active. Entrenchment of major streams and rivers occurred early with series of paired terraces developed. Post-glacial fluvial terraces have been discussed by Henderson (1959), Jones (1961), Mathews (1978) and Burns (1986) (Table 10). Henderson mentioned two sets of paired terraces on the Wapiti south of Grande Prairie, and considered that they are related to terraces seen at Watino, and further north along the Smoky. He suggested that the development of terraces might be related to an expansion of Cordilleran ice into the headwaters of the Smoky and Wapiti. Jones (1961) noted both paired and unpaired terraces on the Wapiti river south of Beaverlodge, with high level terraces between 690 and 700 m, a paired set between 685 and 690 m, and a lower pair between 640 and 655 m. He traced the upper paired terrace along the Wapiti and Smoky to Watino, citing examples south of Grande Prairie and Goodwin, and estimated the gradient of this terrace to increase from 1 m/ km along the Wapiti to 2m/ km along the Smoky. These are comparable to the gradients of the modern river. Mathews (1978) suggested that paired terraces found 60 m above the modern Peace River might be related to those described by Henderson (1959) at Watino. Burns (1986) reports a survey of the terraces at Watino, showing the river level at 377 m, a low terrace at 391 m, a middle terrace at 420 m, and a high terrace at 475 m. A well-preserved wapiti (*Cervus elaphus)* skeleton was excavated from gravel of the middle terrace. Collagen from bone was carbon dated at 9075±305 B.P. (S-2614) and 9920±220 B.P. (AECV-272C). The skeleton was fully articulated and thus provides a reliable

Table 10:- Terrace elevations, Grande Prairie area

Location	Terrace	Altitude (m.a.s.l)	Source
Wapiti, south of Beaverlodge	highest (unpaired)	695	Jones (1961)
	1st paired	685-690	as above
	2nd paired	640-645	
	river level	585	
Wapiti, south of Grande Prairie	1st paired	580	Jones (1961)
	2nd paired	550	this study
	river level	525	
Wapiti, near confluence with Smoky	1st paired	540	Jones (1961)
	river level	470	as above
Watino	high terrace	475	Burns (1986)
	1st paired	420	as above
	2nd paired	390	as above
	river level	375	as above

Elevations are estimated from topographic maps, apart from the data of Burns (1986) which was obtained by topographic survey methods.

minimum date for development of the middle terrace. Burns relates this date to those of 10,200±100 B.P. (GSC-2895) and 10,200±100 B.P. (GSC-2902) on bison bone from a gravel pit elsewhere on the same terrace (Churcher 1984).

A radiocarbon date of 4540±230 B.P. (GSC-2802) on charcoal from a terrace at an altitude of 550 m south of Grande Prairie has been reported (Lowdon and Blake 1979, Jackson and Pawson, 1984) (Table 2). This overlies a palaeosol, and underlies alluvium with prominent fire-bands. This terrace is probably equivalent to the lower paired terrace described by Jones (1961), and may be correlated to the lowest terrace at Watino.

Aeolian sedimentation probably commenced shortly after deglaciation and lake drainage, before vegetation stabilised the land surface. Halsey (1989) notes that dunes found on the middle terrace south of Grande Prairie appear to be truncated by terrace development, and thus were initiated prior to approximately 9,990 B.P. South of Grande Praire sedimentation in a large dune is bracketed by the dates 2030±90 B.P. (GSC-4177, on organics overlying a brunisolic palaeosol) and 4030±180 (AECV-627C, on organic detritus in silts underlying dune sands). Halsey (1989) suggests that these sediments represent a reactivation of aeolian sedimentation, possibly following local fires. Also active following drainage of pro-glacial lakes were the processes that developed the hummocky topography associated with lake sediments in the north of the map area. These are thought to be related to mass movement following lake drainage and river entrenchment, and thus occurred shortly after lake drainage. The final stage of geological evolution in the area consisted of establishment of major rivers at their current level, colluviation of steep slopes in river valleys, and infilling of depressions with clay, and organic sediments.

Bobrowsky *et al.* (1988) reported a date of 7,300±110 B.P. (AECV-583C) on wood from sands 5 m above the modern Peace River to the north of the Grande Prairie map sheet. This suggests that rivers had cut down to close to their modern level by this time.

Summary- geological history

The following sequence of Quaternary events is proposed for the Grande Prairie area (summarised in Figure 75):-

1. Sedimentation in fluvial systems took place in the Middle Wisconsinan, and possibly earlier

2. Ice from the Rocky Mountains covered the southwestern part of the 83M map sheet, either prior to the Late Wisconsinan, or early in the Late Wisconsinan

3. Following retreat of mountain ice, the entire area was covered by the Late Wisconsinan Laurentide Ice Sheet, which did not coalesce with mountain ice.

4. As the Laurentide ice retreated, pro-glacial lakes developed. Four phase of lake development are recognised.

5. Following drainage of pro-glacial lakes, rivers became established in their modern channels. Terraces developed close to 10,000 B.P., and the rivers cut down close to the modern level by 7,300 B.P. A period of aeolian sedimentation and dune development took place, finishing some time prior to 2,000 B.P.

Comparison with regional models

Pre-glacial sediments in Alberta have been discussed by a number of workers. Fenton (1984) identifies five non-glacial intervals in the Pleistocene, three in the Early and Mid Pleistocene, and two in the Late Pleistocene. The earlier events have only been identified in southern Alberta and Saskatchewan; but the Osler non-glacial interval and the Watino non-glacial interval are suggested to be present at the Watino section. The Osler non-glacial interval is

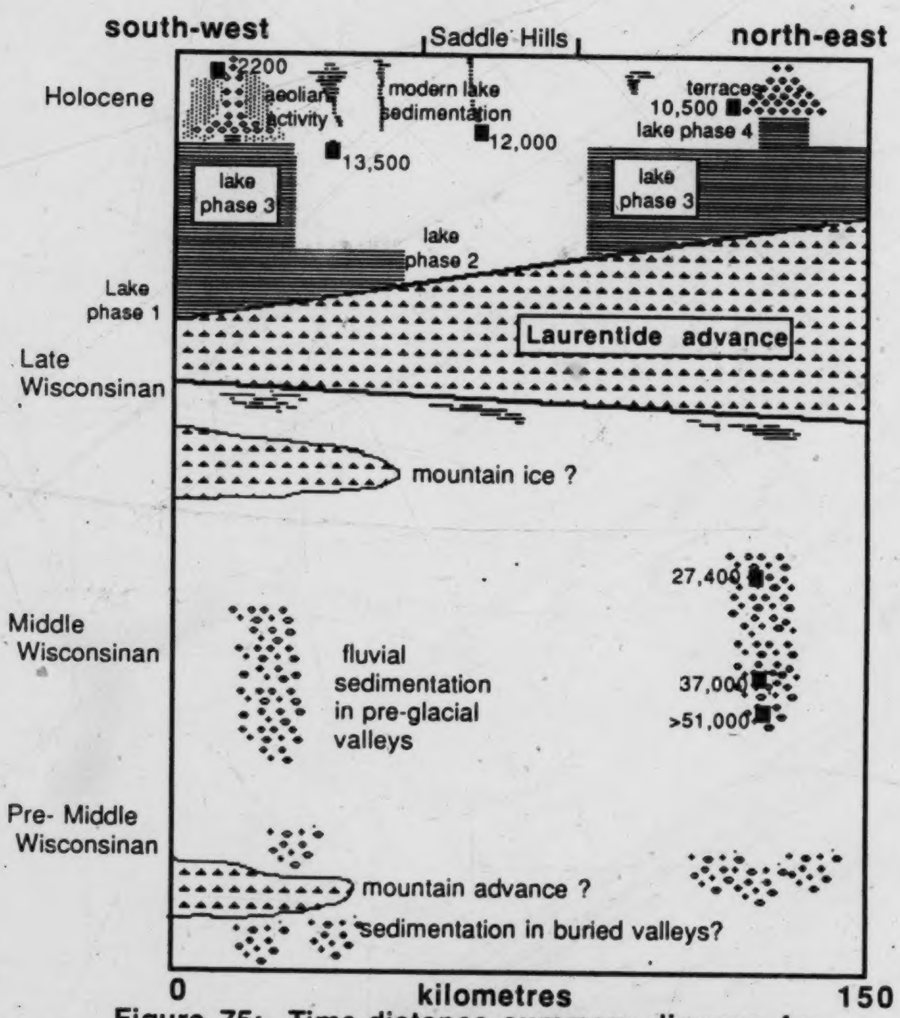

south-west
Saddle Hills
north-east
Holocene
2200
aeolian activity
modern lake sedimentation
12,000
13,500
terraces
10,500
lake phase 4
lake phase 3
lake phase 3
lake phase 2
Lake phase 1
Laurentide advance
Late Wisconsinan
mountain ice ?
Middle Wisconsinan
27,400
fluvial sedimentation in pre-glacial valleys
37,000
>51,000
Pre- Middle Wisconsinan
mountain advance ?
sedimentation in buried valleys?
0
kilometres
150

Figure 75:- Time-distance summary diagram for 83 M map sheet

Figure represents transect from NE to SW corners of sheet. Dates are approximate, see Table 2 for exact numbers thought to be Sangamonian, and its presence at Watino is based on a supposed unconformity between basal gravel and overlying sediments dated as Middle Wisconsinan; and faunal remains and wood beyond the range of carbon dating in the basal gravel. Recent investigations suggest that the sequence at Watino is conformable, and amino acid ratios from wood from the basal gravels show that these sediments are Middle Wisconsinan (Liverman *et al.* 1988, 1989). Thus there is no evidence of non-glacial sediments older than Middle Wisconsinan in the field area or adjacent areas although such sediments may exist.

Non-glacial gravels have been identified throughout central and northern Alberta, and are generally assigned to the "Saskatchewan sands and gravels". This term was defined by Rutherford (1937), and Stalker (1968), and probably encompasses a wide range of fluvial deposits, both in age and in environment of deposition (Catto 1987b). Such sediments are generally considered to be Early or Mid Pleistocene, but the evidence presented here suggests that gravels fulfilling the criteria of Stalker (1968) may be as young as Middle Wisconsinan. Because of the loose definition of the Saskatchewan sands and gravels, it is meaningless to attempt to assign the sediments seen in the Grande Prairie area to this unit.

When comparing the stratigraphy and geological history outlined above with those suggested by other workers in the region, the major point of conflict is in the number of Laurentide glacial events. Jones (1961) found evidence of a single Laurentide glaciation, but Mathews (1978), working northeast of the map sheet, identified two tills, and older gravels containing shield clasts indicative of a third Laurentide glaciation. Reimchen and Rutter (1972) identified a single

Laurentide till in the Dawson Creek area, but suggest a second Laurentide advance on the basis of erratics in fluvial sediments. Henderson (1959), working directly east of the Grande Prairie map area, identified four tills in the Sturgeon Lake area. The uppermost till of these was thought to represent a late readvance of the ice sheet depositing the underlying till, and did not extend west into the Grande Prairie map area. St.Onge (1972b) identified two tills in the Fort Assiniboine area. They were separated by fluvial sediments, barren apart from a single piece of wood, dated by radiocarbon methods as Middle Wisconsinan (Table 2).

These models are apparently in conflict with that presented here, and although it is not possible to evaluate all evidence in the field, a closer examination of the stratigraphic data provided by other workers may help resolve the conflicts. Firstly, it is important to note that the only chronologic control on a pre-Late Wisconsinan glacial event is the radiocarbon date on wood reported by St.Onge (1972b). The tills reported by Henderson (1959) are nowhere separated by stratified material. The two tills described by Mathews (1978) are separated by stratified material (undated, and containing no organics) at one locality only. Thus, it is possible that these sequences were deposited entirely in the Late Wisconsinan, with separate tills resulting from minor advances and retreats, or by deposition under differing conditions (see discussion of the Beaverlodge River II and Saddle River sections in Chapter 5, stratigraphic unit C). The sections of St.Onge (1972b) are to the southeast of the map sheet, and it is possible that earlier glacial events took differing flow paths and did not extend west of the Swan Hills. Given that the stratified sediments separating the two till units are barren of organics apart from the single piece of wood dated, it is possible that this wood was reworked, and that the entire sequence was deposited in the Late Wisconsinan.

Attempts to reconcile the conflicting data above will remain speculation until the critical sections are re-examined in the field.

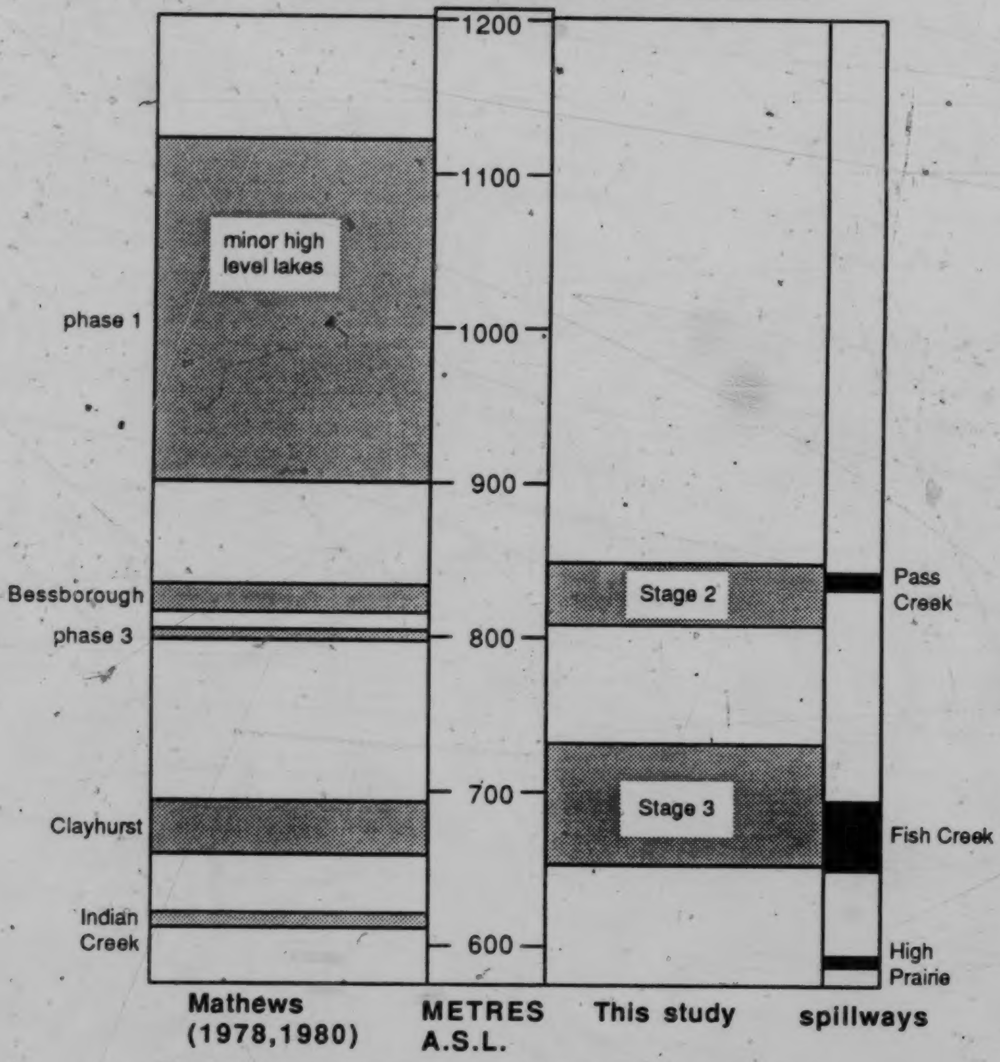
The suggestion that ice from the Rocky Mountains preceded Laurentide advance into the Grande Prairie area in the Late Wisconsinan is in conflict with the views of Mathews (1980), White (1983) and White *et al.* (1985). These authors suggest that the Redwillow fluting field was formed by an advance of Cordilleran ice late in the Late Wisconsinan, with ice moving over lacustrine sediments deposited in pro-glacial lakes dammed by Laurentide ice. The absence of a surface diamicton of Cordilleran provenance, and draping of flutings by lacustrine sediment suggests this hypothesis is incorrect. If such an advance occurred in the Late Wisconsinan, then it must have preceded lake formation. The suggestion that mountain ice preceded Laurentide ice in advancing into the area is in agreement with the pattern seen elsewhere along the mountain front, where mountain ice responds faster to climatic deterioration, and thus is the initial advance onto the prairies (Alley 1973, Stalker and Harrison 1977, Rutter 1984). Rutter (1984) also suggested that the maximum Cordilleran limit on the prairies was related to a pre-Late Wisconsinan advance. North of the field area, Mathews (1980) presented evidence of a late advance, developed on lacustrine sediments and forming a fluting fan similar to that seen in the Redwillow Valley. However, there is no evidence that this was formed at the same time as the Redwillow fluting field.

The Portage Mountain moraine is thought to abut into and be modified by a lake dammed by Laurentide ice to the east (Rutter 1977b, Mathews 1980). Bobrowsky (1988) suggested, on the basis of radiocarbon dates on wood underlying till, that in the Late Wisconsinan the Rocky Mountain Trench, the source of ice in the Peace River valley, was ice free until at least 15,000 B.P. (Table 2). This indicates that the Portage Mountain moraine marks the Late Wisconsinan maximum, and the lake into which it was formed is correlative to the higher of the series of strandlines in the Grande Prairie area. This indicates a restricted late advance of Rocky Mountain ice in the Late Wisconsinan and suggests that the major advance seen in the Grande Prairie area took place prior to the Late Wisconsinan.

White *et al.* (1985) stated that the evidence they present from Boone Lake in the Saddle Hills implies that "ice occlusion in the Peace River area seems to have taken place some time prior to 12,000 years ago" (p.184). Their interpretation is in part based on Mathews' work (Mathews 1978,1980), but the conclusion is incompatible with the evidence. Retreat of the Laurentide ice front from the Saddle Hills probably took place prior to 12,000 B.P., and the ice identified by White *et al.*(1985) was thus an isolated remnant. Even if deglaciation did take place at this date, the evidence provided by White *et al.* (1985) pertains solely to the Laurentide ice sheet. Advance of mountain ice probably preceded Laurentide advance into the area, and thus the work of White *et al.* (1985), although an important palaeoenvironmental record, does not indicate the extent of Late Wisconsinan Cordilleran or montane ice .

The lacustrine stages identified in this study match those of Mathews (1980) (Figure 76). The two major lake levels identified in the Grande Prairie area lie at 840 to 810 m, and 730 to 655 m. Mathews (1980) defines the Bessborough stage of Glacial Lake Peace as being related to four closely spaced shorelines at 830 m, suggested that shorelines rise to the west, indicating isostatic recovery following the removal of Laurentide ice. This is at variance with the

Figure 76:- Comparison of strandlines altitudes defined in this study with those of Mathews (1978, 1980)



Shaded areas represent range of altitudes of shorelines and other strandline features as recorded in each study data of Tokarsky (1967) who suggested a rise from southwest to northeast on a single well defined shoreline in the Grimshaw area, and Henderson (1959) who also suggested a tilt up to the northeast. Jones (1961) suggested a tilt rising to the south based on of the elevation of the boundary between till and lacustrine deposits north and south of the Saddle Hills. Strandlines of two different lake phases are being correlated in this calculation, and thus it is invalid.

The evidence of strandline features observed in the Grande Prairie area does not allow an evaluation of shoreline tilt, as few clearly developed continuous strandlines are found. Thus it is unclear how to account for isostatic tilt in the Grande Prairie area. If the figure of Mathews (1980) is used (0.4 m/ km rise to the west) is used then the Bessborough shorelines should be at an altitude of 800 m in the Beaverlodge area. If those of Tokarsky are used (0.3 m/ km rise to the northeast) , then the altitude of Bessborough shorelines would be almost identical in the Beaverlodge and Fort St. John areas.

Despite the uncertainty of the role of isostacy in shoreline altitude it seems likely that stage 2 of lacustrine development in the Grande Prairie area is identical with the Bessborough stage of Lake Peace defined by Mathews (1980). Mathews suggested that the outlet for this lake was the head of Pass Creek in the Iosegun Lake map area to the southeast of the 83 M sheet, and the lake at this stage is correlated to Iosegun I and II of St. Onge (1972a). The altitude of the spillway at Pass Creek is approximately 835 m. It is located to the east of Bessborough, and thus if shorelines rise to any great degree to the west, would not be compatible with the Bessborough shorelines. If there is little isostatic tilt, the Pass Creek spillway is a possible outlet for the Bessborough stage of Lake Peace, and it is reasonable to correlate stage 2 shorelines in the

Grande Prairie area with this stage. The variation in lake levels seen in the Grande Prairie area can be ascribed to the downcutting of the spillway.

An intermediate phase of Glacial Lake Peace is identified by Mathews (1980) as being related to a series of shorelines in the Charlie Lake map area at approximately 800 m. He suggests that an absence of shorelines between this elevation and the Bessborough shorelines 30 m higher indicates that an alternate outlet opened at this time, rather than downcutting of the Pass Creek spillway. In the Grande Prairie area, the presence of strandline features at intervening elevations does not support this suggestion.

The Clayhurst phase of Glacial Lake Peace is defined by Mathews (1980) on the basis of shorelines between 660 and 690 m elevation in the area of Clayhurst, British Columbia. In the Grande Prairie area, stage 3 of lake development is marked by strandline features between 730 and 655 m. If the isostatic tilt recognised by Mathews (1980) is applied then it appears that these shorelines are too high to correlate with the Clayhurst shorelines. If the isostatic effect declines, or is absent to the east, however, then the shorelines are probably equivalent. The spillway for this lake system is probably a series of meltwater channels at elevations between 650 and 680 m in the area of the Fish Creek moraine, as suggested by Henderson (1959) and Mathews (1980). Such meltwater would have drained north of the Swan Hills into the Lesser Slave Lake area.

The final stage of lake development in the Grande Prairie area, unmarked by strandline features but showing proximal lacustrine sediments is probably related to the Indian Creek stage of Glacial Lake Peace (Mathews 1980). This lake had a level approximately 30 m below that of the Clayhurst stage, and a spillway at an elevation of 590 m near High Prairie, Alberta. This stage of lake development would have covered only the low lying areas of the Peace River valley.

The ice margins suggested by Mathews (1980) in the Grande Prairie area are broadly agreed with in this study. His reconstruction of the Bessborough stage is thought to be in error by showing Cordilleran ice abutting the western edge of the lake, and shorelines to the east of the Saddle Hills suggest that the ice margin in this area should be closer to that for his intermediate stage between Bessborough and Clayhurst stages. Similarly, in the Clayhurst reconstruction, it is felt that there is no evidence for a spillway in the Birch Hills, and the Birch Hills should be portrayed as an island rather than a peninsular. Overall, however, the reconstructions stand up well to closer scrutiny.

Conclusions

The primary objectives of this study were to investigate the distribution of surficial materials in the Grande Prairie, and to outline the Quaternary geological history of the area. This has been achieved by preparing a surficial geology map of the area at a scale of 1:250,000, and defining a stratigraphic sequence of deposition in the Grande Prairie area.

Economic implications

The surficial geology map suggests that slope failure, a common engineering problem in the area, has two main geological causes. Firstly, glaciolacustrine sediments which cover over 50% of the area are clay rich, and prone to failure. The thickness of such sediments is strongly controlled by topography, with significant thicknesses being found in areas which were topographic lows during deglaciation. Such areas include the margins of major valleys, where modern valleys follow the courses of pre-glacial valleys. Such areas are also susceptible to larger scale failure, and it appears that these failures are related to the presence of sand and silt of pre-glacial fluvial sediments at depth. It is also possible that these large scale slope failures are related to bedrock weakness. These hypotheses requires closer observation and testing to be confirmed.

Sand and gravel resources are located throughout the region. This study has failed to locate any significant new areas for aggregate exploitation, although it can be suggested that relatively inaccessible terraces of the Smoky and Peace River may be worthy of investigation. Pre-glacial gravels are generally deeply buried, and thus not usable. Glaciofluvial deposits are rare, but the area around Kamisak Lake appears to contain significant quantities of gravel.

There is a close relationship between soil quality and thickness of lacustrine cover, with most suitable agricultural areas already exploited. There appear to be large areas south of the Wapiti River which may have a reasonably thick cover of lacustrine silt and clay.

Quaternary History

The main conclusions of this study are:-

1. An extensive Middle Wisconsinan fluvial system is present within buried valleys in the area. Older fluvial deposits may be preserved on the margins of these valleys.

2. Ice from the Rocky Mountains affected the southwestern of the map area either early in the Late Wisconsinan or earlier. This ice did not coalesce with Laurentide ice. Only one advance is recognised, but others may have occurred.

3. Only a single major Laurentide advance affected the area, and this occurred in the Late Wisconsinan. The all time maximum Laurentide limit is Late

Wisconsinan and located in the foothills of the Rocky Mountains. It appears that this limit was constrained by altitude, rather than obstruction from ice in the Rocky Mountains.

4. The Late Wisconsinan Laurentide ice sheet was thin, and its margin dammed pro-glacial lakes. The flow in the area was strongly affected by topography, but flow on a regional scale was from northeast to southwest. Evidence of southerly flow from a plains ice divide or dome located over the Caribou Hills was not recognised and is precluded by clast lithology data.
5. During deglaciation, most glacigenic sediment originally deposited as till was remobilised as sub-aquatic sediment gravity flows, and thus there is little undisturbed till in the area below the altitude of lacustrine development.
6. Sediment gravity flows derived from the ice front were limited in their role in lacustrine deposition as a result of downslope ice retreat. Most thick sequences of glaciolacustrine sediment show a major input from westerly non-glacial sources.
7. Ice retreat was rapid, and pro-glacial lakes were comparatively short lived.

Suggestions for further work

As is usual with geological research, especially when investigating an area about which little is known, this study has produced more questions than answers. Amongst the areas of study that are of particular interest are:-

1. The pre-glacial sediments of this area will probably produce an interesting Middle Wisconsinan record. The Watino section is known to contain a variety of faunal and floral remains. A reconnaissance by canoe down the Smoky River revealed numerous sections showing a similar stratigraphy, and possibly much more material. Such an investigation may also reveal pre-Middle Wisconsinan sediments at higher levels. Pre-glacial sediments to the west of Watino in the

Dawson Creek/ Fort St. John area also should be investigated in an attempt to locate datable material, as should sections along the Peace and Smoky Rivers to the northeast of the map area

2. The conflict between the history of Laurentide glaciation suggested here, and that proposed by Mathews (1978) and St. Onge (1972b) in adjacent areas indicates that an attempt should be made to re-evaluate the evidence to see if the two models can be reconciled.

3. The relationship between Laurentide ice and ice from the Rocky Mountains has not been unequivocally established in this work. An investigation of the internal structure of flutes in the Redwillow fluting field might produce evidence to support or reject the model produced here, as would a re-examination of the Dawson Creek map sheet to the west, and mapping of the Wapiti sheet to the south.

References

ABER, J.S. 1982. Model for glaciotectonism. Bulletin of the Geological Society of Denmark, **30**: 79-90.

ALLEY, N.F. 1973. Glacial stratigraphy and the limits of the Rocky Mountain and Laurentide ice sheets in south-western Alberta, Canada. Canadian Petroleum Geology Bulletin, **21**: 153-177.

ANTEVS, E. 1925. Retreat of the last ice sheet in eastern Canada. Geological Survey of Canada Memoir 146.

ASHLEY, G.M. 1975. Rhythmic Sedimentation in Glacial Lake Hitchcock. *In* Glaciofluvial and Glaciolacustrine Sedimentation. *Edited by* A.V. Jopling and B.C. McDonald. Society of Economic Paleontologists and Mineralogists, Special Publication 23, pp. 304-320.

ASHLEY, G.M., SHAW, J. and SMITH, N.D. 1985. Glacial Sedimentary Environments. Society of Economic Paleontologists and Mineralogists, Short Course Notes, number 16.

ASTM 1964. Procedure for testing soils. American Society for Testing and Materials, Philadelphia.

BLAKE, W. 1986. Geological Survey of Canada Radiocarbon Dates XXV. Geological Survey of Canada Paper 85-7.

BOBROWSKY, P.T. 1988. Ice free conditions in the Northern Canadian Cordillera at 18 ka. and timing of the Late Wisconsinan. *In* American Quaternary Association, Programs and Abstracts of the 10th Biennial Meeting, Amherst, Massachusetts, p. 108.

BOBROWSKY, P.T., DAMJKAR, E.R., and GIBSON, T.H. 1988. A geological and archæological study of HcQh-6, Peace River, Alberta. Report on file, Archæological Survey of Alberta, Edmonton, Alberta.

BOBROWSKY, P.T., LEVSON, V., LIVERMAN, D.G.E., and RUTTER, N.W. 1987. Quaternary Geology of Northwestern Alberta and Northeastern British

Columbia. XIIth INQUA Congress field excursion A-24. National Research Council. Ottawa, Ontario, Canada, 62 p.

BOSTOCK, H.S. 1970. Physiographic subdivisions of Canada. *In* Geology and Economic Minerals of Canada. *Edited by* R.J.W. Douglas Queens Printer for Canada. Ottawa, pp. 10-30.

BOULTON, G.S. 1971. Till genesis and fabric in Svalbard, Spitsbergen. *In* Till: a symposium. *Edited by* R.P. Goldthwait, Ohio State University Press, Columbus, Ohio. pp. 41-72.

BOULTON, G.S. 1972. Modern Arctic glaciers as depositional models for former ice sheets. Journal of the Geological Society, London, **128**: 361-393.

BOULTON, G.S. 1975. Processes and patterns of subglacial sedimentation: a theoretical approach. *In* Ice Ages: Ancient and Modern, *Edited by* H.E. Wright and J.T. Mosley. Seal House Press, London. pp. 7-43.

BOULTON, G.S. 1978. Boulder shapes and grain-size distributions of debris as indicators of transport paths through a glacier and till genesis. Sedimentology, **25**: 773-799.

BOULTON, G.S., SMITH, G.D., JONES, A.S., and NEWSOME, J. 1985. Glacial geology and glaciology of the last mid-latitude ice sheets. Journal of the Geological Society of London, **142**: 447-474.

BOUMA, A.H. 1962. Sedimentology of some flysch deposits. Elsevier, Amsterdam.

BROOKFIELD, M.E. 1984. Eolian sands. *In* Facies Models, *Edited by* R.G. Walker. Geoscience Canada reprint series. 1, pp. 91-103.

BURNS, J.A. 1986. A 9000-year old wapiti (*cervus elaphus*) skeleton from northern Alberta, and its implications for the early Holocene environment. Geographie Physique et Quaternaire, **XL**: 105-108.

CARLSON, V.A., and HACKBARTH, D.A. 1974. Bedrock topography of the Grande Prairie area, NTS 83 M. Map of the Research Council of Alberta, Edmonton, Alberta.

CATTO, N.R. 1983. Loess in the Cypress Hills, Alberta, Canada. Canadian Journal of Earth Sciences, **20**: 1159-1167.

CATTO, N.R. 1984. Glacigenic deposits at the Edmonton Convention Centre, Edmonton, Alberta. Canadian Journal of Earth Sciences, **21**: 1473-1482.

CATTO, N.R. 1986. Quaternary sedimentology and stratigraphy, Peel Plateau and Richardson Mountains, Yukon and North-west Territories. Unpublished Ph.D. thesis, Department of Geology, University of Alberta.

CATTO, N. R. 1987a. Lacustrine sedimentation in a proglacial environment, Caribou River Valley, Yukon, Canada. Boreas, **16** : 197-206.

CATTO, N.R. 1987b. Unpublished glacial geology laboratory manual, Department of Geology, University of Alberta.

CHURCH, M and GILBERT, R. 1975. Proglacial fluvial and lacustrine environments. *In* Glaciofluvial and Glaciolacustrine Sedimentation. *Edited by* A.V. Jopling and B.C. McDonald. Society of Economic Paleontologists and Mineralogists Special Publication 23, pp. 22-101.

CHURCHER, C.S. and WILSON, M. 1979. Quaternary mammals from the eastern Peace River District, Alberta. Journal of Paleontology, **53**: 71-76.

CLAGUE, J.J., EVANS, S.G., and BLOWN, I.G. 1985. A debris flow triggered by the breaching of a moraine dammed lake, Klattasine Creek, British Columbia, Canadian Journal of Earth Sciences, **22**: 1492-1503.

COLEMAN, J.M. and GAGLIANO, S.M. 1965. Sedimentary structures: Mississippi River deltaic plain. *In* Primary sedimentary structures and their hydrodynamic interpretation. *Edited by* G.V. Middleton. Society of Economic Paleontologists and Mineralogists, Special Publication 12, pp. 133-148.

COLLINSON, J.D. 1971. Some effects of ice on a river bed. Journal of Sedimentary Petrology, **41**: 557-564.

DAVID, P.P. 1977. Sand dune occurrences of Canada. National Parks Branch, Canada, Department of Indian and Northern Affairs, contract 74-230, Report.

DAWSON, G.M. 1881. Report on an exploration from Port Simpson on the Pacific coast to Edmonton on the Saskatchewan, embracing a portion of the northern part of British Columbia and the Peace River country. Geological Survey of Canada, Report of Progress, 1879-1880, pt.B, pp. 1-177.

DIONNE, J.C. 1979. Ice action in the lacustrine environment; a review with particular reference to subarctic Quebec. Earth Science Review, **15**: 185-212.

DOMACK, E.W. 1983. Facies of late Pleistocene glacial-marine sediments on Whidbey Island, Washington: an isostatic glacial-marine sequence. *In* Glacial-Marine Sedimentation. *Edited by* B.F. Molnia. Plenum, New York, pp. 535-570.

DOMACK, E. W. and LAWSON, D.E. 1985. Pebble fabric in an ice-rafted diamicton. Journal of Geology, **93**: 577-591.

DOWDESWELL, J. 1986. The distribution and character of sediments in a tidewater glacier, southern Baffin Island, N.W.T., Canada. Arctic and Alpine Research, **18**: 45-56.

DOWDESWELL, J. and SHARP, M.J. 1986. Characterization of pebble fabrics in modern terrestrial glacigenic sediments. Sedimentology, **33**: 699-710.

DREDGE, L.A. and THORLIEFSON, L.H. 1987. The Middle Wisconsinan History of the Laurentide ice sheet. Geographie Physique et Quaternaire, **XLI**: 215-236.

DREIMANIS, A. 1976. Tills, their origin and properties. *In* Glacial Till: an interdisciplinary study. *Edited by* R.F.Legget. Royal Society of Canada Special Publication 12, pp. 11-50.

DREIMANIS, A. 1982. Two origins of the stratified Catfish Creek Till at Plum Point, Ontario, Canada. Boreas, **11**: 173-180.

DYKE, A.S., DREDGE, L.A., and VINCENT, J.S. 1982. Configuration and dynamics of the Laurentide Ice Sheet during the Late Wisconsin maximum. Geographie Physique et Quaternaire, **36**: 5-14.

DYKE, A.S and PREST, V.K. 1987. Late Wisconsinan history of the Laurentide Ice Sheet. Geographie Physique et Quaternaire, **XLI**: 237-263.

EVENSON, E.B., DREIMANIS, A., and NEWSOME, J.W., 1977. Sub-aquatic flow till: a new interpretation for the genesis of some laminated till deposits. Boreas, **6**: 115-133.

EYLES, C.H. and EYLES, N. 1983. Sedimentation in a large lake: a reinterpretation of the late Pleistocene stratigraphy at Scarborough Bluffs, Ontario, Canada. Geology, **11**: 146-152.

EYLES, N., 1979. Facies of supraglacial sedimentation on Icelandic and Alpine temperate glaciers. Canadian Journal of Earth Sciences, **16**: 1341-1361

EYLES, N and MIALL, A.D. 1984. Glacial Facies. *In* Facies Models. *Edited by* R.G.Walker. Geological Association of Canada. Geoscience Canada Reprint Series 1: 15-38

FAEGRI, K. and IVERSEN, J. 1975. Textbook of Pollen Analysis. Blackwell Scientific Publications, Oxford.

FENTON, M. 1984. Quaternary Stratigraphy of the Canadian Prairies. *In* Quaternary Stratigraphy of Canada, *Edited by* R.J. Fulton. Geological Survey of Canada Paper 84-10, pp. 57-68.

FERGUSON, T.A. 1980. Productivity and predictability of resource yield: aboriginal controlled burning in the boreal forest. M.A. thesis, Department of Anthropology, University of Alberta. Edmonton, Alberta.

FISHER, D.A., REEH, N. and LANGLEY, K. 1985. Objective reconstruction of the Late Wisconsin Laurentide ice sheet, and the significance of deformable beds. Geographie Physique et Quaternaire, **39**: 229-238.

FLADMARK, K.R. 1981. Paleo-Indian artifacts from the Peace River district. B.C.

Studies, **48**: 124-135.

FLADMARK, K.R., DRIVER, J.C., and ALEXANDER, D. 1988. The fluted point component at Charlie Lake Cave (HbRf 39), British Columbia. American Antiquity, **53**: 371-385.

FOLK, R.L. and WARD, W.C. 1957. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology, **27**: 3-26

FRYBERGER, S.G., AHLBRANDT, T.S. and ANDREWS, S. 1979. Origin, sedimentary features, and significance of low angle eolian "sand sheet" deposits, Great Sand Dunes National Monument and vicinity, Colorado. Journal of Sedimentary Petrology, **49**: 733-746.

GIBBARD, P. 1980. The origin of stratified Catfish Creek till by basal melting. Boreas, **9**: 71-85.

GILBERT, R. and DESLOGES, J.R. 1987. Sediments of ice dammed self draining Ape Lake, British Columbia. Canadian Journal of Earth Sciences, **24**:1735-1747.

GRAVENOR, C.P. 1985. Magnetic and pebble fabrics of glaciomarine diamictons in the Champlain Sea, Ontario, Canada. Canadian Journal of Earth Sciences, **22**: 422-424.

GRAVENOR, C. P. 1986. Magnetic and pebble fabrics in subaquatic debris-flow deposits. Journal of Geology, **94**: 683-698.

GRAVENOR, C.P. and KUPSCH, W.O. 1959. Ice disintegration features in western Canada. Journal of Geology, **67**: 48-64.

GUSTAVSON, T.C., ASHLEY, G.M. and BOOTHROYD, J.C. 1975. Depositional sequences in glaciolacustrine deltas. *In* Glaciofluvial and Glaciolacustrine Sedimentation. *Edited by* A.V. Jopling and B.C. McDonald. Society of Economic Paleontologists and Mineralogists Special Publication 23, pp. 264-280.

HACKBARTH, D. 1977. Hydrogeology of the Grande Prairie area. Alberta

Research Council report 76-4.

HALDORSEN, S. and SHAW, J., 1982. The problem of recognising melt-out till. Boreas, **10**: 261-277

HALSEY, L.A. 1989. Sedimentology and development of the Grande Prairie dune field, Alberta, Canada. M.Sc thesis, Department of Geology, University of Alberta, Edmonton, Alberta. 173 p.

HALSEY, L.A., CATTO, N.R., and LIVERMAN, D.G.E. 1987. Sedimentary facies and sequences of parabolic dunes, Alberta, Canada. XII International Congress of the International Union for Quaternary Research, Programme with abstracts, Ottawa, National Research Council. Ottawa, p. 181.

HENDERSON, E.P. 1959. Surficial geology of the Sturgeon Lake map area, Alberta. Geological Survey of Canada Memoir 303.

HENDERSON, P.J. 1988. Sedimentation in an esker system influenced by bedrock topography near Kingston, Ontario. Canadian Journal of Earth Sciences, **25**: 987-999.

HOLTER, M.E. 1972. Gravel and sand resources of the Grande Prairie area. Alberta Research Council open file report, 1972-14.

HOLTZ, R.D. and KOVACS, W.D. 1981. An Introduction to Geotechnical Engineering. Prentice-Hall, New Jersey.

JACKSON, L.E and PAWSON, M. 1984. Alberta radiocarbon dates. Geological Survey of Canada Paper. 83-25.

JOHNSTON, W.A. 1933. Quaternary Geology of North America in relation to the migration of Man. *In* The American Aborigines. *Edited by* D. Jenness. University of Toronto Press, Toronto, pp. 11-45.

JONES, J.F. 1961. Surficial Geology and related problems, Beaverlodge area, Alberta, Canada. M.Sc thesis, Department of Geology, University of Western Ontario. London, Ontario.

JONES, J.F. 1966. Geology and Groundwater of the Peace River District.

Alberta Research Council Bulletin 16.

JOPLING, A.V. and WALKER, R.G. 1969. Morphology and origin of ripple-drift cross-laminations, with examples from the Pleistocene of Massachusetts. Journal of Sedimentary Petrology, **38**: 971-984.

KOCUREK, G and NIELSON, J. 1986. Conditions favourable for the formation of warm-climate aeolian sand sheets. Sedimentology, **33**: 795-816.

KUENEN, Ph.H. 1951. Mechanics of varve formation and the action of turbidity currents. Geologiska Föreningens i Stockholm Förhandlinger, **73**: 69-84.

KULIG, J.J. 1985. A glaciolacustrine sedimentation model. M.Sc. thesis, Department of Geology, University of Alberta, Edmonton, Alberta.

LAWSON, D.E. 1979a. A sedimentological analysis of the western terminus of the Matanuska Glacier, Alaska. United States Army Cold Regions Research and Engineering Laboratory Report, 79-9.

LAWSON, D.E. 1979b. A comparison of the pebble orientations in ice and deposits of the Matanuska Glacier, Alaska. Journal of Geology, **87**: 629-645.

LAWSON, D.E. 1981. Distinguishing characteristics of diamictons at the margin of the Matanuska Glacier, Alaska. Annals of Glaciology, **2**: 78-84.

LAWSON, D.E. 1982. Mobilisation, movement, and deposition of active subaerial sediment flows, Matanuska Glacier, Alaska. Journal of Geology, **90**: 279-300.

LEVSON, V. and RUTTER, N.W. 1986. A facies approach to the stratigraphic analysis of Late Wisconsinan sediments in the Portal Creek area, Jasper National Park, Alberta. Géographie Physique et Quaternaire, **XL**: 129-144.

LICHTI-FEDEROVITCH, S. 1975. Plant megafossils from Mid-Wisconsin sediments in west-central Alberta. *In* Report of Activities, Pt. C, Geological Survey of Canada Paper 75-1C, pp. 85-90.

LIVERMAN, D.G.E. 1981. Sedimentation and drainage history in an ice dammed lake, St.Elias Mountains, Yukon. M.Sc. thesis, Department of Geology, University of Alberta, Edmonton, Alberta.

LIVERMAN, D.G.E, CATTO, N.R. and RUTTER, N.W. 1988. Laurentide glaciation in west-central Alberta; a single (Late Wisconsinan) event. Geological Association of Canada, Abstracts with programme,St.John's, Newfoundland, p A-74.

LIVERMAN, D.G.E, CATTO, N.R. and RUTTER, N.W. 1989. *in press* Laurentide glaciation in west-central Alberta; a single (Late Wisconsinan) event. Canadian Journal of Earth Sciences.

LOWDON, J.A. and BLAKE, W. 1979. Geological Survey of Canada radiocarbon dates XIX. Geological Survey of Canada Paper 79-7.

LOWE, D.R. 1976. Subaqueous liquified and fluidized sediment flows and their deposits. Sedimentology, **23**: 285-308.

LOWE, D.R. 1979. Sediment gravity flows: their classification and some problems of its application to natural flows and deposits. *In* Geology of Continental Slopes. *Edited by* L.J. Doyle and O.H. Pilkey, Jr., Special Publication of the Society of Economic Paleontologists and Mineralogists 27, pp. 75-82.

LOWE, D.R. 1982. Sediment gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents. Journal of Sedimentary Petrology, **52**: 279-297.

MACKAY, J.R. 1973. The growth of pingos, western Arctic Coast, Canada. Canadian Journal of Earth Sciences, **10**: 979-1004.

MARK, D.M. 1973. Analysis of axial orientation data, including till fabrics. Bulletin of the Geological Society of America, **84**: 1369-1374.

MARK, D.M. 1974. On the interpretation of till fabrics. Geology, **2**: 101-104.

MARTIN, P.S. 1973. The discovery of America. Science, **179**: 969-974.

MATHEWS, W.H. 1963. Quaternary stratigraphy and geomorphology of the Fort St. John area, northeastern British Columbia. Internal report, B.C. Department of Mines and Petroleum Resources, Victoria.

MATHEWS, W.H. 1972. Quaternary Geology, Charlie Lake, British Columbia. *In* Report of Activities, Part A, Geological Survey of Canada Paper 72-1A, pp. 169-170.

MATHEWS, W.H. 1974. Surface profiles of the Laurentide ice sheet in its marginal areas. Journal of Glaciology, **13**: 37-43.

MATHEWS, W.H. 1978. Quaternary Stratigraphy and geomorphology of the Charlie Lake (94-A) map area. Geological Survey of Canada paper 76-20.

MATHEWS, W.H. 1980. Retreat of the last ice sheets in northeastern British Columbia and adjacent Alberta. Geological Survey of Canada Bulletin 331.

MAY, R.W. 1977. A facies model for sedimentation in the glaciolacustrine environment. Boreas, **6**: 175-180.

MCCABE, A. M. 1986. Glaciomarine facies deposited by retreating tidewater glaciers: an example from the Late Pleistocene of Northern Ireland. Journal of Sedimentary Petrology, **56**: 880-894.

MCCABE, A.M., DARDIS, G.F. and HANVEY, P.M. 1984. Sedimentology of a late Pleistocene submarine-moraine complex, County Down, Northern Ireland. Journal of Sedimentary Petrology, **54**: 716-730.

MCCABE, A. M., DARDIS, G.F. and HANVEY, P M., 1987. Sedimentation at the margins of a late Pleistocene ice-lobe terminating in shallow marine environments, Dundalk Bay, eastern Ireland. Sedimentology, **34**: 473-493.

MCKEE, E.D. 1979. A study of global sand seas. United States Geological Survey Professional Paper 1052.

MCLEARN, F.H. 1918. Peace River Section, Alberta. Geological Survey of Canada Summary Report, 1917, pt.C, pp. 14-21.

MCLEARN, F.H. and KINDLE, E.D. 1950. Geology of Northeastern British Columbia. Geological Survey of Canada Memoir 259.

MEIER, M.F. 1987. Iceberg calving glaciers: ice dynamics and its influence on sedimentation patterns. XII International Congress of the International Union for Quaternary Research, Programme with abstracts, National Research Council. Ottawa, p. 224.

MIALL, A.D. 1977. A review of the braided-river depositional environment. Earth Science Reviews, **13**: 1-62.

MILLS, H.H. 1977. Basal till fabrics of modern alpine glaciers. Geological Society of America Bulletin, **88**: 824-828.

MILLS, H.H. 1984. Clast orientation in Mount St. Helens debris-flow deposits, North Fork Toutle River, Washington. Journal of Sedimentary Petrology, **54**: 626-634.

MOLLARD, J.D. 1983. The origin of reticulate and orbicular patterns on the floor of Lake Agassiz. *In* Glacial Lake Agassiz. *Edited by* J.T. Teller and L. Clayton. Geological Association of Canada Special Paper 26, pp. 355-374.

MORAN, S.R., CLAYTON, L., HOOKE, R.LeB., FENTON, M.M. and ANDRAISHEK, L.D. 1980. Glacier bed landforms of the prairie region of North America. Journal of Glaciology, **25**: 457-477.

MOSS, E.H. 1952. Grassland of the Peace River region, western Canada. Canadian Journal of Botany, **31**: 448-470.

MÜLLER, E.H. 1983. Dewatering during lodgement of till. *In* Tills and Related Deposits. *Edited by* E.B. Evenson, Ch. Schluchter, and J. Rabassa. A.A. Balkema, Rotterdam. pp. 13-18.

NARDIN, T.R., HEIN, F.J., GORSLINE, D.S. and EDWARDS, B.D. 1979. A review of mass movement processes, sediment and acoustic characteristics, and contrasts in slope and base-of-slope systems versus canyon-fan-basin systems. *In* Geology of Continental Slopes. *Edited by* L.J. Doyle and O.H. Pilkey, Jr. Society of Economic Paleontologists and Mineralogists, Special

Publication 27, pp. 61-73.

NORTH, M.E.A. 1976. A plant geography of Alberta. Department of Geography, University of Alberta. Edmonton, Alberta.

ODYNSKY, Wm. 1958. U-shaped dunes and effective wind direction in Alberta. Canadian Journal of Soil Science, **38**: 56-62.

ODYNSKY, Wm. and NEWTON, J.D. 1950. Soil Survey of the Rycroft and Watino Sheets. Alberta Research Council Report 15.

ODYNSKY, Wm., WYNNYK, A. and NEWTON, J.D. 1956. Soil survey of the Grande Prairie and Sturgeon Lake sheets. Alberta Research Council Report 18.

ODYNSKY, Wm, LINDSAY J.D., REEDER, S.W. and WYNNYK, A. 1961. Soil survey of the Beaverlodge and Blueberry Mountain sheets. Alberta Research Council Report 20.

OVENSHINE, A.T. 1970. Observations of iceberg rafting in Glacier Bay, Alaska and identification of ice-rafted deposits. Bulletin of the Geological Society of America, **81**: 891-894.

PARISEK, R. 1969. Glacial ice-contact rings and ridges. Geological Society of America Special Paper, **123**: 49-102.

PATERSON W.S.B. 1969. The Physics of Glaciers. Pergamon Press, Oxford.

POWELL, R.D. 1981. A model for sedimentation by tidewater glaciers. Annals of Glaciology, **2**: 129-134.

POWELL, R.D. 1983. Glacial-marine sedimentation processes and lithofacies of temperate tidewater glaciers, Glacier Bay, Alaska. *In* Glacial-Marine Sedimentation. *Edited by* B.F. Molnia. Plenum. New York, pp. 185-232.

POWELL, R.D. 1984. Glacimarine processes and inductive lithofacies modelling of ice-shelf and tidewater glacier sediments based on Quaternary examples. Marine Geology, **57**: 1-52.

POWERS, M. 1953. A new roundness scale for sedimentary particles. Journal of Sedimentary Petrology, **23** : 117-119.

RAHMANI, R.A. and LERBEKMO, J.F. 1975. Heavy mineral analysis of Upper Cretaceous and Paleocene sandstones in Alberta, and adjacent areas of Saskatchewan. *In* The Cretaceous System in the Western Interior of North America. *Edited by* W.G.E. Caldwell. Geological Association of Canada Special Paper 13, pp. 607-632.

RAPPOL, M. 1985. Clast-fabric strength in tills and debris flows compared for different environments. Geologie en Mijnbouw, **64**: 327-332.

RAUP, H.M. 1941. Botanical problems in Boreal America. Botanical Review, **7**: 147-248.

REEVES B.O.K. 1973. The nature and age of the contact between the Laurentide and Cordilleran Ice Sheets in the Western Interior of North America. Arctic and Alpine Research, **5**: 1-16.

REIMCHEN, T.H.F. 1968. Pleistocene Mammals from the Saskatchewan Gravels in Alberta, Canada. M.Sc. thesis, Department of Geology, University of Alberta Edmonton, Alberta.

REIMCHEN, T.H.F. 1980. Surficial Geology, Dawson Creek. Geological Survey of Canada Map, 1467 A.

REIMCHEN, T.H.F. and RUTTER, N.W. 1972. Quaternary Geology, Dawson Creek, B.C. Report of Activities, pt.A, Geological Survey of Canada Paper 72-1A, pp. 176-177.

RINGBERG, B. 1984. Cyclic lamination in proximal varves reflecting the length of summers during Late Weischel in southern Sweden. *In* Climatic changes on a yearly to millenial basis. *Edited by* N.A. Mörner and W. Karlén. D.Reidel, Dortrecht, pp. 57-62.

ROED, M.A. 1975. Cordilleran and Laurentide multiple glaciation, west-central Alberta. Canadian Journal of Earth Sciences, **12**: 1493-1515.

ROED, M.A., MOUNTJOY, E.W., and RUTTER, N.W. 1967. The Athabasca Valley Erratics Train, Alberta and Pleistocene Ice Movements across the Continental Divide. Canadian Journal of Earth Sciences, **4**: 625-632.

ROTHLISBERGER, H., 1972. Water pressure in intra and subglacial channels. Journal of Glaciology, **79**: 177-203.

ROWE, J.S., 1972. Forest Regions of Canada. Canadian Forest Publication 1300. Department of Environment, Ottawa.

RUST, B.R. 1977. Mass flow deposits in a Quaternary succession near Ottawa, Canada: diagnostic criteria for subaqueous outwash. Canadian Journal of Earth Sciences, **14**: 175-184.

RUST, B.R. and ROMANELLI, R. 1975. Late Quaternary subaqueous outwash deposits near Ottawa, Canada. *In* Glaciofluvial and Glaciolacustrine Sedimentation. *Edited by* A.V. Jopling and B.C. McDonald. Society of Economic Paleontologists and Mineralogists Special Publication 23, pp. 177-192.

RUST, B. and KOSTER, E. 1984. Coarse alluvial deposits. *In* Facies Models. *Edited by* R.G. Walker, Geoscience Canada reprint series 1, pp. 53-69.

RUTHERFORD, R. 1930. Saskatchewan sands and gravels in central Alberta. Transactions of the Royal Society of Canada, IV: series 3, **31**: 115-124.

RUTTER, N.W. 1976. Multiple glaciation in the Canadian Rocky Mountains with special emphasis on northeastern British Columbia. *In* Quaternary Stratigraphy of North America. *Edited by* W.C. Mahaney. Dowden, Hutchinson and Ross. Stroudsberg, Pennsylvania, pp. 409-440.

RUTTER, N.W. 1977a. Multiple Glaciation in the area of Williston Lake, British Columbia. Geological Survey of Canada, Bulletin 273.

RUTTER, N.W. 1977b. Methods of terrain evaluation, Mackenzie transportation corridor, N.W.T., Canada. Earth Surface Processes, **2**: 295-308.

RUTTER, N.W. 1981. Relationship between Late Pleistocene Laurentide and Cordilleran glaciations, Canada. *In* Quaternary Glaciations in the Northern

Hemisphere. *Edited by* V. Sibrava and F.W. Shotton, Geological Survey. Prague, IGCP Project 73/1/24, Report No. 6, pp. 205-218.

RUTTER, N.W. 1984. Pleistocene history of the western Canadian ice free corridor. *In* Quaternary Stratigraphy of Canada- a Canadian contribution to IGCP Project 24. *Edited by* Fulton R.J., Geological Survey of Canada Paper 84-10. pp. 50-56.

SCHMOLL, H. 1961. Orientation of phenoclasts in laminated glaciomarine deposits. United States Geological Survey Professional Paper, **424C**: C192-C195.

SELWYN, A.R.C. 1877. Report on exploration in British Columbia in 1875. Geological Survey of Canada Report of Progress, 1875-76, pp. 25-86.

SHAW, J. 1975. Sedimentary successions in ice marginal lakes. *In* Glaciofluvial and Glaciolacustrine Sedimentation. *Edited by* A.V. Jopling and B.C. McDonald. Society of Economic Paleontologists and Mineralogists, Special Publication 23, pp. 281-383.

SHAW, J. 1979. Genesis of the Sveg tills and Rogen moraines of central Sweden: a model of basal meltout. Boreas, **8**: 409-426.

SHAW, J. 1982. Melt-out till in the Edmonton area, Alberta, Canada. Canadian Journal of Earth Sciences, **19**: 1548-1569.

SHAW, J. 1983. Forms associated with boulders in melt-out till. *In* Tills and Related Deposits. *Edited by* E.B. Evenson, Ch. Schluchter, and J. Rabassa. A.A. Balkema, Rotterdam. pp. 3-13.

SHAW, J. 1987. Glacial sedimentary processes and environmental reconstruction based on lithofacies. Sedimentology, **34**: 103-116.

SHILTS, W.W. and DEAN, W.E. 1975. Permafrost features under arctic lakes, District of Keewatin, Northwest Territories. Canadian Journal of Earth Sciences, **12**: 649-662.

ST. ONGE, D.A. 1968. Quaternary geology and geomorphology, Whitecourt map area, Alberta. Geological Survey of Canada Paper 68-1A, pp. 186-188.

ST. ONGE, D.A. 1972a. La stratigraphie du Quaternaire des environs de Fort Assiniboine, Alberta, Canada. Revue de géographie de Montréal, **26**: 153-163.

ST. ONGE, D.A. 1972b. Sequence of glacial lakes in north-central Alberta. Geological Survey of Canada Bulletin 213.

STALKER, A.McS. 1968. Identification of Saskatchewan gravels and sands. Canadian Journal of Earth Sciences, **5**: 156-163.

STALKER, A.McS. 1984. Field use of macrofeatures for correlating tills and estimating their ages: a review. *In* Quaternary Dating Methods, *Edited by* W.C. Mahaney. Elsevier. Amsterdam, pp. 311-322.

STALKER, A.McS and HARRISON, J.E. 1977. Quaternary glaciation of the Waterton-Castle River region of Alberta. Canadian Petroleum Geology Bulletin, **25**: 882-906.

STANLEY, K.O. 1974. Morphology and hydraulic significance of climbing ripples with superimposed micro-ripple-drift cross-lamination in Lower Quaternary lake silts, Nebraska. Journal of Sedimentary Petrology, **44**: 472-483.

STELCK, C.R. 1955. Cardium Formation in the foothills of northeastern British Columbia. Transactions of the Canadian Institute of Mining and Metallurgy, **58**: 132-139.

STELCK, C.R. and WALL, J.H. 1954. Kaskapau Foraminifera from Peace River area, of western Alberta. Research Council of Alberta Report 68.

STOTT, D.F. 1975. The Cretaceous System in northeastern British Columbia. *In* The Cretaceous System in the Western Interior of North America. *Edited by* W.G.E. Caldwell. Geological Association of Canada Special Paper 13, pp. 441-467.

STURM, M., and MATTER, A. 1978. Turbidites and varves in Lake Brienz, Switzerland: deposition of clastic detritus by density currents. *In* Modern and ancient lake sediments. *Edited by* A. Matter and M.E.Tucker. Special Publication of the International Association of Sedimentologists, 2, Blackwell, Oxford. pp. 147-168.

SUGDEN, D.E. and JOHN, B.S. 1976. Glaciers and landscape, a geomorphological approach. Edward Arnold, London.

TELLER, J.T. 1987. Proglacial lakes and the southern margin of the Laurentide Ice Sheet. *In* North America and adjacent oceans during the last deglaciation. *Edited by* W.F. Ruddiman W.F., and H.E. Wright Jr.. The Geology of North America, **K-3**, Geological Society of America, Boulder, Colorado, pp. 39-69.

THOMPSON, G.S.P. and CONNEL, R.J. 1985. Iceberg drop, dump, and grounding structures from Pleistocene glacio-lacustrine sediments, Scotland. Journal of Sedimentary Petrology, **55**: 243-249.

TOKARSKY, O. 1967. Geology and groundwater resources of the Grimshaw/ Cardinal Lake area, Alberta. M.Sc thesis. Department of Geology, University of Alberta. Edmonton, Alberta.

TWARDY, A.G. and CORNS, I.G.W. 1980. Soil Survey and Interpretation of the Wapiti Map area. Alberta Research Council Bulletin 39.

VISSER, J.N.J. 1982. Upper Carboniferous glacial sedimentation in the Karoo Basin near Prieska, South Africa. Palaeogeography, Palaeoclimatology and Palaeoecology, **30**: 63-92.

VISSER, V.N.J. 1983. Submarine debris flow deposits from the Upper Carboniferous Dwyka Tillite Formation in the Kalahari Basin, South Africa. Sedimentology, **30**: 511-523.

VISSER, J.N.J. 1984. Glacial-marine sedimentation in the late Palaeozoic Karoo Basin, Southern Africa. *In* Glacial-Marine Sedimentation. *Edited by* B.F. Molnia. Plenum Press, New York, pp. 667-701.

VIVIAN R. and BOCQUET G. 1973. Sub-glacial cavitation phenomena under the Glacier d'Argentière, Mont Blanc, France. Journal of Glaciology, **12**:

439-459.

WALKER, R.G. 1984. Turbidites and associated coarse clastic deposits. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada reprint series 1, pp. 171-188.

WALKER, R.G. and CANT, D. 1984. Sandy fluvial systems. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada reprint series. 1, pp 71-90.

WARREN, P.S. and STELCK, C.R. 1940. Cenomanian and Turonian faunas in Pouce Coupe district, Alberta and British Columbia. Transactions of the Royal Society of Canada, 3rd series, **34**: 143-152.

WASHBURN,, A.L. 1973. Periglacial processes and environments. Edward Arnold, London.

WESTGATE, J.A., FRITZ, P., MATHEWS, J.V., KALAS, L. and GREEN, R. 1971. Sediments of Mid-Wisconsin age in west-central Alberta; geochronology, insects, ostracodes, mollusca and the oxygen isotope composition of molluscan shells. Geological Society of America, program with Abstracts, Rocky Mountain Section Annual Meeting, 3, p. 419.

WESTGATE, J.A., FRITZ, P., MATHEWS, J.V., KALAS, L., DELORME, L.D., GREEN, R., and AARIO, R. 1972. Geochronology and palaeoecology of mid-Wisconsin sediments in west-central Alberta. International Geological Congress, 24th Session, Abstracts, p. 380.

WHITE, J.M. 1983. Late Quaternary geochronology and palaeoecology of the upper Peace River District, Canada. Ph.D. thesis, Department of Archaeology, Simon Fraser University. Burnaby, B.C.

WHITE, J.M., MATHEWES, R.W., and MATHEWS, W.H. 1979. Radiocarbon dates from Boone Lake and their relation to the "ice free corridor" in the Peace River district of Alberta. Canadian Journal of Earth Sciences, **16**: 1870-1874.

WHITE, J.M., MATHEWES, R.W., and MATHEWS, W.H. 1985. Late Pleistocene chronology and environment of the "Ice free corridor" of northwestern

Alberta. Quatemary Research, **24**: 173-186.

WILKINSON, K. 1981. Remnant and early settlement prairies on solonetzic soils in the Peace River District. M.Sc thesis, Department of Biology, University of Calgary, Calgary, Alberta.

WILLIAMS, P.F. and RUST, B.R. 1969. The sedimentology of a braided river. Journal of Sedimentary Petrology, **39**: 649-679.

WOODCOCK, N.H. 1977. Specification of clast fabric shapes using an eigenvalue method. Bulletin of the Geological Society of America, **88**: 1231-1236.

Appendix 1:- Section locations

Under quality, the degree of exposure, and visibility of sedimentary structures is assessed on a qualitative scale of 0 (none), 1 (poor) to 4 (excellent). Abbreviations used include:-

lam. = laminated ; GP= Grande Prairie; 40= highway 40 (similarly 34 etc); nr.=near; trib.=tributary. Where more than one number is given for a section, this reflects work done in more than one field season. Thus section 25.6.5 (1985 field season) is the same as 86.15 (1986 field season). Although confusing, this system is kept so as to be consistent with field notes and sample numbers. For convenience, a list of 1986 sections and equivalent 1985 section numbers is given following the detailed list, and also a list of named sections from the text, and the equivalent 1985 and 1986 section numbers. An asterisk (*) indicates sections located out of the 83 M map area.

Section number	location (UTM)	Description	quality	samples	fabric
16.6.1/ 86.5/Simonette section	MM250109 Simonette River	20 m sand and silt/ 5m gravels/ bedrock	4	y	n
16.6.2	MM234042 nr. Economy Creek	2m+ clay and fine sand	2	n	n
16.6.3	ML224997 S Economy Crk	diamicton	1	n	n
16.6.4	ML225993 S Economy Crk	10 cm+ sand/ 2m lam. clays/ 1m diamicton	2	n	n
16.6.5	MM230002 Economy Creek	1m f.sand/ 2m+lam clays	2	n	n
16.6.6	MM232170 nr. Goodwin	clays	1	n	n
16.6.7	MM313189 Debolt Creek	1.5m stony lam.clays/ 0.1m gravel/ 1m+ diamicton	3	n	n
16.6.8	MM240190 H.34, E of Smoky	2m+ X bedded sand	3	n	n
17.6.1	MM251239 N of 34, E of Smoky	fine sand and silt	1	n	n
17.6.2	MM268238 as above	clayey silts, lam.	1	n	n
17.6.3	MM315244 as above	lam clays and silts	2	n	n
17.6.4	MM270383 as above	sands and silt	1	n	n
17.6.5	MM267383 as above	f-m sand	2	n	n
17.6.6	MM218217 as above	f-m sand	2	n	n
17.6.7	MM234164 as above	f-med sands/ 2m+lam clays	2	n	n
18.6.1	MM349252 as above	clay with stones	1	n	n

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Section number	location (UTM)	Description	quality	samples	fabric
18.6.2	MM338435 Puswaskau R	lam. clays, no stones	1	n	n
18.6.3/ 86.6	MM343438 Puswaskau R.	10m+ diamicton	3	y	y
18.6.4	MM270530 pit E of Smoky	sand and gravel	3	y	n
19.6.1	LM998212 34, nr Glen Leslie	lam. clay and silt	2	n	n
19.6.2	MM069148 S of Glen Leslie	fine sand	2	n	n
19.6.3 86.2	MM007148trib. Bear River	3m+diamicton	3	y	y
19.6.4	LM9601568 km E of GP	0.6 m lam clays/1 m+ lam diamicton/ sand/ bedrock	3	n	n
19.6.5	LM748091Spring Creek	2m+lam clay, rare stones	2	n	n
20.6.1	LM615073 Pipestone Creek	2m+lam clays/ diamicton/ gravel/ bedrock	3	y	n
20.6.2	LM595126 trib Pipestone Ck	clays, no stones	1	n	n
20.6.3	LM582085as above	lam. clays	1	n	n
20.6.4/ 86.9	LM582073 as above	1.5m lam clays, stones/ 1.1m+ diamicton	3	y	y
20.6.5	LM582030 N of Wapiti	1m sand/diamicton	3	n	n
20.6.6	LM614035 bank of Wapiti	3 m sands/ bedrock	2	n	n
20.6.7	LM550044 N of Wapiti	2m+ f. sand	2	n	n
21.6.1/ 86.1, Beaverlodge River III	LM495130 Beaverlodge R	8m silts & clay/ 1.5 m diamicton	4	y	y
24.6.1	LM449170 S of Beaverlodge	0:4m lam clays	1	n	n
24.6.2	LM431098 nr Halcourt	lam clay with stones	1	n	n
24.6.3	LM386067 Redwillow R.	5m diamicton/ gravel & sand/ bedrock	3	y	y
25.6.1	LM370328 Beaverlodge R	1m+ silt, no stones	2	n	n
25.6.2	LM301330 nr Goodfare	diamicton	1	n	n
25.6.3	LM242292 flute nr. Goodfare	1m+diamicton	1	y	n
25.6.4	LM310265nr. Goodfare	stony diamicton	1	n	n
25.6.5/ 86.15, Albright section	LM403262 Beaverlodge R.,	2m silts,gravels/ 5m diamicton	4	y	y
25.6.6	LM518192S Saskatoon Hill	lam clays with rare stones	1	n	n
25.6.7	LM533205 Saskatoon Hill	beaches	0	n	n
25.6.8	LM532213 As above	4m f-med sand	3	y	n
25.6.9	LM648189 W Saskatoon Lake.	5m lam clays/ 2m+ lam.dimicton	3	n	n
26.6.1	LM84009040 S of GP	fine sand	1	n	n
26.6.2/ 86.57, Bear Creek section	LM820200 Bear Ck	3m lam clays and diamicton	3	n	n
26.6.3	LM802280 Bear Ck	3m silt & sand/ .5m+ lam clays	2	n	n
26.6.4	LM820190 Bear Ck, N of GP	sand & silt	2	n	n
26.6.5	LM884183 dugout NE of GP	5m lam clay/ 2m lam diamicton/	3	y	y
27.6.1	LM785014 nr. Grovedale	f-m sand	1	n	n
27.6.2	LM777015 nr. Grovedale	m sand/ lam clay	2	n	n
27.6.3	LM773028 pit nr. Grovedale	sand/ 10m gravel & sand	3	y	n
28.6.1	LL880997 40 S of Wapiti	m-c sand in dunes	2	y	n
28.6.2	LM878024 as above	lam clays, rare stones	1	n	n
28.6.3	LM880040 Wapiti, S of GP	gravel	2	n	n

Section number	location (UTM)	Description	quality	samples	fabric
28.6.4/ 26.7.1	LM975130 Bear Ck SE of GP	3m lam clay/ 10m diamicton/ 30 m bedrock	3	y	n
28.6.5	LM966128 as above	m-sand/ lam clay	2	n	n
30.6.1	LM855050 pit S of GP	gravel	2	n	n
30.6.2/ 86.3	LM845045 pit on 40 S of GP	20 m sand/ gravel	4	y	n
30.6.3	LM853037 S of Wapiti, 40	gravel/ bedrock	2	n	n
30.6.4	LM851134 Bear Ck, SGP	4m+ lam clays	2	n	n
1.7.1	LM924182 S of 34 E of GP	sand mounds	1	n	n
1.7.2	MM104136 N of Wapiti, S 34	m sands	1	n	n
1.7.3	MM118136 S of Bezanson	lam clay, no stones	1	n	n
1.7.4	MM054210 pit nr Bezanson	clay/ diamicton	1	n	n
1.7.5	MM053242 E Kleskun Hill	gravel in strand line	2	n	n
1.7.6	MM047244 Kleskun Hill park	bedrock-sst, shale, coal	3	y	n
1.7.7	MM054251 N Kleskun Hill	1m gravels& sand/ bedrock	2	n	n
1.7.8	MM006252 NW Kleskun Hill	lam diamicton	2	n	n
1.7.9	MM023277 as above	sand & lam clay	2	n	n
1.7.10	MM014270 N Kleskun Hill	0.7m+ lam clay with stones	1	n	n
1.7.11	MM098308 as above	lam? clay with stones	1	n	n
1.7.12	MM106315 nr. Fitzsimmons	clay, with stones	1	n	n
1.7.13	MM107353 Kleskun Ck.	2m banded diamicton/ 3m massive diamicton	3	n	n
1.7.14/ 86.8	MM122356 Kleskun Creek	10 m diamicton (colluvium)	3	y	y
2.7.1	LM909245 E of Clairmont	1.5m+ lam clay with stones	3	n	n
2.7.2	LM910270 Clairmont Lake	meltwater channel	1	n	n
2.7.3	LM920408 S of Webster	clays with stones	1	n	n
2.7.4	LM923408 as above	f.sand/ clay	1	n	n
2.7.5	LM937408 SE of Webster	clay with stones	1	n	n
2.7.6	LM946408 as above	diamicton	1	n	n
2.7.7	LM956407 as above	1.5m sand & gravel/ diamicton	2	n	n
2.7.8	LM961392 as above	strandline	1	n	n
3.7.1	LM848376 NW of Sexsmith	lam? clay with stones	1	n	n
3.7.2	LM847368 as above	diamicton	1	n	n
3.7.3	LM796347 Prairie Ck	1.5 m silt & clay/ .15 strat. diamicton/ diamicton	3	n	n
3.7.4/ 86.14	LM690349 Niobe Creek	lam clay/ 10 m diamicton	3	y	y
3.7.5/ 86.10	LM645350 Bear R	.2 m clay/ 9m+diamicton	3	y	y
3.7.6	LM638469 N of La Glace	.2m lam clay/ .4m+diamicton	1	n	n
3.7.7	LM681487 as above	1 m med sand/ diamicton	2	n	n
3.7.8	LM716535 N Le Glace	sandy clay & clayey sands	1	n	n
3.7.9	LM695510 as above	clay rich diamicton	1	n	n
3.7.10	LM703470 as above	0.2m gravel/ diamicton	1	n	n
3.7.11	LM733135 N of Dimsdale	lam clay	1	n	n
3.7.12	LM742121 Spring Creek	lam clay with stones/ bedrock	1	n	n

Section number	location (UTM)	Description	quality	samples	fabric
4.7.1	LM650262 Cutbank Lake	lam clay/ 1 mdiamicton & lam clay /1m diamicton/bedrock	3	y	n
4.7.2	LM630289 Colquhoun Ck.	1m+lam diamicton/ 1m sand 3m+ massive diamicton	3	n	n
4.7.3	LM550250 S of Poplar Hill	clay rich diamicton	1	n	n
4.7.4	LM550240 N Saskatoon Hill	1m f-m sand	1	n	n
4.7.5	LM549233 as above	diamicton	1	n	n
4.7.6	LM437070 Halcourt	clayey sand	1	n	n
4.7.7/ 86.55/86.56	LM512101 Beaverlodge R Huallen Beaverlodge River I	2.5m silt/ 3m lam clay/ 20m diamicton/ 5m gravel	4	y	y
5.7.1	LM368187 Hayfield	lam clay with stones	1	n	n
5.7.2/ 86.16	LM364095 Rio Grande	1.8m lam clay/ 1.5m+ diamicton	3	y	n
5.7.3	LM275068 Redwillow R.	sandy silts (2m)	2	n	n
5.7.4	LM209054 W of Hazelmere	lam clay	1	n	n
5.7.5	LM209050 as above	.4 m lam clay/1m+ diamicton	2	n	n
5.7.6	LM180011 as above	diamicton	1	n	n
5.7.7	LM175011 as above	diamicton	1	n	n
5.7.8/ 86.20	LL418982 Wapiti/ Redwillow	.7 m lam clay/ 15 m diamicton/ bedrock	3	y	y
5.7.9	LM452029 as above	f-m sand	2	n	n
5.7.10	LM465012 as above	X bedded sands	3	n	n
5.7.11	LL483993 as above	gravels	1	n	n
6.7.1	LM165271 W of Goodfare	.2 lam silt/ diamicton	2	y	n
6.7.2	LM158258 Steeprock Creek	lam clay	1	n	n
6.7.3	LM248215 NW Kamisak Lake	diamicton	1	n	n
6.7.4	LM265215 as above	lam clay	1	n	n
6.7.5	LM221199 as above	lam clay with stones	1	n	n
6.7.6	LM220157 W Kamisak Lake	gravels	1	n	n
6.7.7	LM210145 as above	gravel/ clay with stones	1	n	n
6.7.8/ 86.19	LM213068 Redwillow R	.55 m lam clay/ .3m strat. diamicton/ 4m diamicton/ bedrx	4	y	y
6.7.9	LM276104 W Rio Grande	lam clay	1	n	n
6.7.10	LM252117 as above	stone pile	1	n	n
6.7.11	LM360133Rio Grande	stone pile	1	n	n
7.7.1	LM375368 N of Hythe	1.5 m lam clay	1	y	n
7.7.2	LM376384 as above	.8m + lam clay with stones	2	n	n
7.7.3	LM328426 W Brainard	lam clay with stones	1	n	n
7.7.4	LM117517 2 N Demmit	1m lam clay/ 2m+diamicton	1	n	n
7.7.5	LM143520 N Demmit	.5m lam clay/ 2.5m diamicton	2	y	n
7.7.6 86.54	LM108560 E Swan Lake	.1m lam clay/ 2m diamicton/ 20m bedrock	2	y	y
7.7.7	LM135535 as above	clay/ diamicton	2	y	n
7.7.8	LM167461 S of Demmit	lam clay with stones	1	n	n
7.7.9	LM167457 as above	.5 m diamicton/ bedrock	1	n	n
7.7.10	LM182436 as above	1m+sand & gravel/ 1-2m sand	3	y	n
7.7.11	LM135380 W of Lymburn	lam clay/ diamicton	1	n	n

Section number	location (UTM)	Description	quality	samples	fabric
7.7.12	LM129382 as above	sand/ lam clay with stones	1	n	n
8.7.1	LM383358 Hythe	lam clay, few stones	1	n	n
8.7.2	LM436358 E of Hythe	diamicton	1	n	n
8.7.3	LM504356 Poplar Hill	lam clay with stones	1	n	n
8.7.4	LM516388 nr. La Glace Lake	no strandlines	0	n	n
8.7.5	LM541482 E Valhalla	bedrock	2	n	n
8.7.6	LM569491 SE of Homestead	ice thrust bedrock	4	y	y
8.7.7/ 86.13	LM572493 as above	3m+ diamicton	3	y	y
8.7.8	LM586482 Homestead	sand, silt, clay with stones	2	n	n
8.7.9	LM582509 as above	0.5m sand/1m+ lam silts	2	n	n
8.7.10	LM584522 Saddle Hills	lam clay/bedrock and sands	1	n	n
8.7.11	LM569548 E Homestead	diamicton	1	n	n
8.7.12	LM558548 as above	.5 m+ lam clay with stones	2	n	n
8.7.13	LM553540 as above	.5m diamicton/ bedrock	2	n	n
8.7.14	LM511483 Valhalla	1.5m lam clay few stones	3	n	n
9.7.1*	FS809772 Pouce Coupe	3m lam clay	3	n	n
9.7.2	LM351912 Henderson Creek	lam clay, few stones	1	n	n
9.7.3	LM376912 49 W Gordondale	massive silts, few stones	2	n	n
9.7.4	LN618074 Hamelin Creek	.5m lam silt/ 3m+diamicton	3	n	n
10.7.1 86.52	LM125880 Sergeant Creek	5m lam clay/ 2m+ diamcton	3	y	y
10.7.2	LM190868 S of Bay Tree	conglomerate bedrock, sands	3	y	n
10.7.3	LM180943 Henderson Creek	2m gravel & sand/ 20m bedrock	2	n	n
10.7.4	LM182928 NE of Bay Tree	1m+ lam clay, no stones	1	n	n
10.7.5/ 86.51, Henderson Creek section	LM232902 Henderson Creek	4m lam clay/ 7m diamicton	4	y	y
10.7.6/ 86.46/ 86.47/ 86.48 Pouce Coupe section	LN136005. Pouce Coupe R.	20m lam clay/ 18m diamicton/ bedrock	4	y	y
10.7.7	LN130020 W Pouce Coupe R	silt & clay, massive	1	n	n
11.7.1	LM125849 Sergeant Creek	2m lam silt/ clay diamicton	2	n	n
11.7.2	LM313946 SE of Bonanza	clay, no stones	1	n	n
11.7.3	LM316946 as above	1.5m+ lam clay with stones	2	n	n
11.7.4*	LN398142 N Blueberry Hill	diamicton?	1	n	n
11.7.5/ 86.33	LN643895Ksituan R	2m sand & silt/ .5m gravel/ 5m diamicton	3	y	y
11.7.6	LM652859 49 S of Whitburn	clay diamicton	1	n	n
11.7.7	LM66483849 W Spirit River	lam clay with stones	1	n	n
11.7.8	LM772865 as above	lam clay with stones	1	n	n
11.7.9/ 86.30	LM777882 Howard Ck	20m diamicton/ 50m bedrock	3	y	y
11.7.10	LM759905 Ksituan R	3m diamicton/ .6m sand & gravel	3	y	n
12.7.1	LM680830 W of Spirit River	clays with stones	1	n	n
12.7.2	LM830780 Spirit R.	2m sand & silt/ 2.5m+ diamicton	3	n	n
12.7.3/ 86.34	LM830620 Saddle R. Woking	4m gravel & sand/ 1m lam clay with stones/ 3m diamicton	3	y	y
12.7.4	LM880630 near Saddle River	sand and gravel	2	n	n

Section number	location (UTM)	Description	quality	samples	fabric
12.7.5	LM900630 Saddle River	3m sand & silt/ gravel	3	n	n
12.7.6/ 86.35	LM940610 Brayburn Creek	2m diamicton	3	y	y
12.7.7	MM125630 Kakut Creek	diamicton	1	n	n
12.7.8/ 86.21	MM185550733,Bad Heart R	diamicton, 3m, alluvium	3	y	y
17.7.1	LM980925 SE Dunvegan	lam clay	1	n	n
17.7.2	MM001963 SEof Dunvegan	.5 m silty clay/lam silts & sand	2	n	n
17.7.3	MM078922 SE of Dunvegan	X lam clay &silt	3	y	n
17.7.4	MM096922 as above	clay & silt	2	n	n
17.7.5	MM128953 pit S of Peace	lam silt/20m gravel	2	n	n
17.7.6	MM140875 Saddle R,	4m diamicton and sand	3	y	n
17.7.7	MM142866 as above	5 m silt & sand/ 7m diamicton	3	y	n
17.7.8/ 86.26	MM142868 as above	20m banded diamicton	3	y	y
17.7.9	MM038781 Saddle R	3m gravels/ diamcton	2	n	n
17.7.10	LM967795 E of Rycroft	5m lam clay no stones	2	n	n
18.7.1	MN009073 Hines Ck.	diamicton	2	n	n
18.7.2/ 86.28, Hines Creek section	LN996064 Hines Ck ski hill	5m lam silt/ diamicton	4	y	n
18.7.3	LN927040 W of Hines Ck	lam silt & clay	1	n	n
18.7.4	MN044053 Boucher Ck	1.5 m alm clay	3	n	n
18.7.5*	MN052086 2, N of Dunvegan	2m+lam clay with stones	2	n	n
18.7.6/ 86.29	MN128020ck w of Dunvegan	5m+ diamicton	3	y	y
18.7.7	MN139019as above	banded diamicton	3	y	n
18.7.8	MM003990 above Dunvegan	diamicton/ sand/bedrock	3	n	n
19.7.1	MM032998 as above	lam clay with stones	1	n	n
19.7.2	MN098098 N Peace River	X lam sand and silt	3	n	n
Peace River section					
19.7.3*	MN070265 S of Fairview	20m+ diamicton	3	y	y
19.7.4	MM358992 SE of Lothrop	silt and sands	1	n	n
19.7.5	MN360030 E of Lothrop	1m+ lam silt and clay	3	n	n
19.7.6	MM025978 Dunvegan bridge	30m gravel and sand	4	n	n
20.7.1	LM916872 N of Rycroft	lam clay, no stones	1	n	n
20.7.2	LM878900 NW Rycroft	lam clay and silt	1	n	n
20.7.3	LM828911 Howard Ck	30m + clay & silt, rare stones	3	n	n
20.7.4	LN775068 Hamelin Ck	3m+ clay, few stones	2	n	n
20.7.5*	LN780080 Hamelin Ck.	diamicton	1	n	n
20.7.6/ 86.31	LN775074 as above	3.5m lam clay, no stones	4	y	n
20.7.7	LN858067 W of Peace R	3m+ sand and gravel/ diamicton	3	n	n
20.7.8	LM707984 Poplar Ridge	lam clay, no stones	1	n	n
20.7.9/ 86.32	LN664063 Hamelin Ck. N of Blueberry Mtn	4m lam silt and clay/ 2m+ diamicton	4	y	y
Hamelin Creek section					
21.7.1	LM952860 Spirit R. N Rycroft	4m silts, rare stones	3	y	n
21.7.2	LM990860 NW Rycroft	lam clay/ gravel/ diamicton	1	n	n

Section number	location (UTM)	Description	quality	samples	fabric
21.7.3	MM016858 NE Prestville	lam clay no stones	1	n	n
21.7.4/ 86.27	MM001776 Saddle R	3m sand & gravel/ 8m diamicton	4	y	y
21.7.5	MM181791 E Wanham	lam clay, no stones	1	n	n
21.7.6	MM210792 Belloy	lam silty clays, no stones	1	n	n
21.7.7	MM308853 Vixen Ck Codesa	2m lam silt/ 4m massive silt	3	y	n
21.7.8	MM242856 N Belloy	lam clay & silt, no stones	1	n	n
21.7.9	MM093890 N Wanham	lam clay, no stones	1	n	n
21.7.10	MM082890 as above	2m + lam clay & silt	2	n	n
21.7.11	LM976828 NE Rycroft	lam clay, no stones	1	n	n
22.7.1	LM918732 S Rycroft	1.5m+ lam clay, no stones	2	n	n
22.7.2/ 86.25	LM789605 Saddle R, Woking	3m gravel/ 4m+diamicton	3	y	y
22.7.3	LM684605 as above	clays with stones	1	n	n
22.7.4	LM763606 as above	10m diamicton	3	n	n
22.7.5	LM722648 as above	bedrock	1	n	n
22.7.6	LM700641 as above	clay with stones	1	n	n
22.7.7	LM682642 as above	3-4m diamicton & sand/ bedrock	3	y	n
22.7.8	LM781638 as above	2m+ strat diamicton	3	n	n
22.7.9	LM 802723 Spirit Ridge	benches	0	n	n
22.7.10	LM882732 Silverwood	clay? over bedrock	1	n	n
22.7.11	MM128723 Birch Hills	bedrock	1	n	n
22.7.12	MM192726 as above	1m lam clay/ diamicton	1	n	n
22.7.13	MM159646 W Peoria	2m+ lam clay rare stones	2	n	n
22.7.14/ 86.24	MM156646 as above	5m diamicton	3	y	y
24.7.1	LM905572 S Woking	diamicton	1	n	n
24.7.2	LM895530 Saddle Hills	diamicton	1	n	n
24.7.3	LM895517 as above	diamicton	1	n	n
24.7.4	LM894497 Saddle Hills	diamicton	1	n	n
24.7.5 86.18	LM880427 N Sexsmith	3m+ gravel and sand	3	n	n
24.7.6/ 86.17 Beaverlodge River II	LM487129 Beaverlodge R SW Huallen	1m lam silt/ 7m diamicton/ 5m gravel, sand, diamicton	4	y	y
25.7.1	LM530483 E Homestead	.3 diamicton/ bedrock	2	n	n
25.7.2	LM523602 Saddle Hills, N of Homestead	diamicton/ bedrock	1	n	n
25.7.3	LM523640 as above	diamicton	1	n	n
25.7.4	LM486644 Boone Lake	diamicton	2	n	n
25.7.5	LM388542 nr Spring Lake	2m+ sands	3	n	n
27.7.1	LM196204 W Mount Valley	diamicton	1	y	n
27.7.2	LM122183 as above	diamicton	1	n	n
28.7.1	LM941439 Webster	diamicton	1	n	n
28.7.2	LM963457 as above	diamicton	1	n	n
28.7.3	LM995438 E Webster	clay?/ diamicton	1	n	n
28.7.4	MM025437 as above	strandlines?	0	n	n
28.7.5	MM092437 as above	.5m lam clay/ diamicton	2	n	n

Section number	location (UTM)	Description	quality	samples	fabric
28.7.6	MM231434 Smoky R,	diamicton	1	n	n
28.7.7	MM233438 as above	gravel	3	n	n
28.7.8	MM244487 pit E Bad Heart	2m gravels	2	n	n
28.7.9	MM222517 E Bad Heart	diamicton	1	n	n
28.7.10/ 86.22	MM206532 as above	gravel/ diamicton	2	y	y
28.7.12	MM182558 Bad Heart R. N Bad Heart	lam clay/ 10m diamicton/ sand/ bedrock	3	n	n
28.7.13	MM175558 SE Heart Valley	lam clay	1	n	n
28.7.14	MM256598 SE Peoria	5m+ diamicton	3	n	n
28.7.15	MM322584 Smoky SE Peoria	bedrock	1	n	n
28.7.16	MM336595 as above	m-f sand, 4m	2	n	n
28.7.17	MM338673 Birch Hills	.5m gravel/ diamicton	2	n	n
28.7.18*	MM390723 Birch Hills	benches	0	n	n
29.7.2	LM747752 Spirit R.	5m+ lam clay	1	n	n
29.7.3	LM721769 Spirit Ridge	strandlines	0	n	n
29.7.4	LM703770 W Spirit R	.3m clay/ bedrock?	1	n	n
29.7.5	LM590767 N Saddle Hills	2m+ diamicton	2	y	n
29.7.6	LM584741 as above	1m diamicton/ bedrock	2	n	n
29.7.7	LM530800 as above	diamcton/ bedrock	2	y	n
29.7.8	LN512012 NE Blueberry Hill	clay, few stones	1	n	n
29.7.9	LN508041 as above	diamicton	1	n	n
29.7.10	LN512047 as above	clay with stones	1	n	n
29.7.11	LN473069 as above	lam clay?/ 1.5 mdiamicton/rock	2	n	n
29.7.12/ 86.53	LN407072 as above	3m+ diamicton	3	y	y
29.7.13	LN382064 as above	1m sand &gravel/ 2.5m+ diamicton	3	n	n
29.7.14	LN277044 NE Bonanza	2m lam clay	2	y	n
29.7.15	LM260980 Bonanza	diamicton?	1	n	n
30.7.1	LM426878 Gordondale	clay, rare stones	1	n	n
30.7.2	LM410878 Henderson Ck	1m+ diamicton	2	y	n
30.7.3	LM410913 NE Gordondale	thin clay/ 2.5m diamcton	1	n	n
30.7.4	LM300867 N Saddle Hills	diamicton	1	n	n
30.7.5	LM325774 as above	1m+ diamicton	1	n	n
30.7.6*/ 86.41	LM090660 Tupper R.	.1m lam clay/ 4.5m+ diamicton	3	y	y
30.7.7	LM111663 Gundy	gravels	3	y	n
1.8.1	MM075170 S of 34	clay, no stones	1	n	n
1.8.2	MM090170 S of 34	silt and sands	1	n	n
1.8.3	MM160230 N of 34	clay	1	n	n
86.7	MM205220 Smoky 34 bridge	diamicton/ 8m+sand &silt/ gravel	3	n	y
86.11*	FR768916 S.Redwillow R.	diamicton	2	y	n
86.12*	FS728393 One Island Lak	diamicton	2	y	n
86.23	MM206532 E Bad Heart	3m lam silt and clay	3	y	n
86.40*	FS530810 Kiskatinaw R	5m diamicton/ 35 m bedrock	2	n	n
86.42*	LM086660 Tupper Ck.	diamicton	3	y	y
86.43*	FT530040 Kiskatinaw Park	lam clay/ diamicton	2	n	n

Section number	location (UTM)	Description	quality	samples	fabric
86.44*	FS140760 East Pine	50m+ silt, clay, diamicton	3	n	n
86.45	FS300870 N Groundbirch	gravels and diamicton	2	y	n
86.49	LN075155 Doe Ck	1 m+diamicton/ silt & sand	3	y	n
86.50	LN140005 Pouce Coupe R	8m lam silt and clay, few stones	3	y	n

1986 sections

1986 number	equivalent 1985 section
86.1	21.6.1
86.2	19.6.3
86.3	30.6.2
86.5	16.6.1
86.6	18.6.3
86.7	new section
86.8	1.7.14
86.9	20.6.4
86.10	3.7.5
86.11	new section
86.12	new section
86.13	8.7.7
86.14	3.7.4
86.15	25.6.5
86.16	5.7.2
86.17	24.7.6
86.18	24.7.5
86.19	6.7.8
86.20	5.7.8
86.21	12.7.8
86.22	28.7.10
86.23	new section
86.24	22.7.14
86.25	22.7.3
86.26	17.7.8
86.27	21.7.4
86.28	18.7.2
86.29	18.7.6
86.30	11.7.9

1986 number	equivalent 1985 section
86.31	20.7.6
86.32	20.7.9
86.33	11.7.5
86.34	12.7.3
86.35	12.7.6
86.40	new section
86.41	30.7.6
86.42	new section
86.43	new section
86.44	new section
86.45	new section
86.46	10.7.6
86.47	new section
86.48	10.7.6
86.49	new section
86.50	new section
86.51	10.7.5
86.52	10.7.1
86.53	29.7.12
86.54	7.7.6
86.55	4.7.7
88.56	4.7.7
88.57	26.6.2

Sections named in text

Section name	Section numbers
Hines Creek section	86.28, 18.7.2
Peace River section	19.7.2
Simonette River section	86.5, 16.6.1
Beaverlodge River I section	88.55, 86.56, 4.7.7.
Beaverlodge River II section	86.17, 24.7.6
Beaverlodge River III section	86.1,21.6.1
Henderson Creek section	86.51, 10.7.5
Pouce Coupe section	86.46, 10.7.6
Hamelin Creek section	86.32, 20,7.9
Albright section	86.15, 25.6.5
Bear Creek section	86.57, 26.6.2

Appendix 2

The following is a summary of fabric data collected, with, for each location, the type of fabric (unimodal, girdle, bimodal, polymodal), S1, S2, and S3 values, and an estimate of modal orientations (if different from the S1 values as is the case for non unimodal distributions). N/A= not available. See Appendix 1 for section names.

Section number	source	n	type	S1	trend,plunge	S2	orientation	S3	orientation	mode
24.6.3	massive diamicton	25	unimodal	.62	032 27	.23	N/A	.15	N/A	032
26.6.5	massive diamicton	25	weak poly	.40	099 20	.31	N/A	.29	N/A	085/140
19.7.3	massive diamicton	25	bimodal	.59	353 07	.32	N/A	.09	N/A	353/130
86.1	lam clay, assoc.1	29	polymod.	.54	087 04	.44	355 02	.02	243 85	045/085
86.2	massive diamict	25	weak poly	.48	318 06	.38	052 36	.14	219 53	318
86.6	diamict-colluvium?	25	weak bi	.53	071 18	.29	337 09	.18	022 69	060
86.8	massive diamicton	25	unimodal	.59	045 24	.22	305 21	.19	178 57	045
86.9	mass diamict, base	25	weak bi	.45	132 01	.41	222 11	.14	037 79	131/050
86.9	mas diamict, top	25	girdle	.48	175 15	.35	276 36	16	066 50	175
86.10	strat. diamicton	25	unimodal	.65	095 25	.24	001 8.3	.11	254 63	95
86.13	massive diamicton	25	unimodal	.73	155 13	.21	246 3	.06	351 77	165
86.14	massive diamicton	25	weak uni	.59	122 7.7	.22	029 20	.20	232 69	122
86.15	unit A-0	25	weak bi	.51	068 10	.33	N/A	16	N/A	067/120
86.15	unit A-2	15	weak poly	.60	247 19	.22	147 25	18	010 57	247
86.15	unit A-11	25	weak poly	58	259 17	.27	165 10	15	046 70	258
86.17	unit BRII-1	25	bimodal	.59	181 16	.29	082 28	12	298 57	200/110
86.17	unit BRII-2	25	bimodal	58	112 11	.37	210 35	04	008 52	112/270
86.17	unit BRII-4	25	weak uin	50	139 14	.36	230 04	14	337 75	139
86.17	unit BRII-7, base	25	weak bi	.48	246 11	.37	155 5	15	040 78	246/310
86.17	unit BRII-7, top	25	bimodal	54	265 11	37	356 3	08	099 78	265/010
86.17	unit BRII-8	25	weak unii	62	261 9	30	352 11	07	133 76	260
86.19	base mass. diamict	25	weak uni	50	258 13	34	165 15	16	028 70	258
86.19	top mass. diamict	25	unimodal	67	179 5	23	270 11	09	064 78	179
86.20	massive diamicton	25	weak bi	45	226 11	45	317 03	09	061 78	226/317
86.21	massive diamicton	25	bimodal	61	351 21	31	084 06	08	188 68	310/030
86.22	diamict	25	weak uni	50	182 7	34	273 06	16	046 80	182
86.24	massive diamicton	25	bimodal	55	068 22	30	159 01	15	251 68	68/159
86.25	massive diamicton	25	weak bi	52	224 18	29	N/A	19	N/A	224/135
86.26	unit SA-1	25	girdle	57	185 39	28	074 23	15	322 42	185

Section number	source	n	type	S1	trend,plunge	S2	orientation	S3	orientation	mode
86.26	unit SA-2	25	girdle	.53	215 18	.40	306 3	.07	046 71	215/270
86.27	diamicton	25	weak uni	.60	178 12	.29	85 12	.10	311 73	178
86.29	massive diamicton	25	bimodal	.58	036 04	.35	126 3	.07	257 85	036/090
86.30	massive diamicton	25	unimodal	.62	109 08	.31	199 00	.07	291 82	109
86.32	massive diamicton	25	unimodal	.67	205 13	.23	115 02	.10	015 77	220
86.33	massive diamicton	25	unimodal	.67	208 13	.25	113 23	.08	323 63	208
86.34	massive diamicton	25	weak bi	.55	173 00	.30	83 06	.15	265 83	173/300
86.35	massive diamicton	25	girdle	.49	052 05	.40	142 05	.11	279 82	045
86.41	massive diamicton	25	weak bi	.49	236 11	.40	144 11	.11	009 74	236/144
86.42	massive diamicton	25	unimodal	.65	157 01	.29	067 08	.06	255 82	157
86.48	massive diamicton	25	unimodal	.68	163 01	.21	074 03	.10	278 87	163
86.51	unit H-1, base	25	polymod	.50	067 11	.37	333 17	.13	188 69	270/66
86.51	unit H-1 mid	25	polymod	.43	306 09	.33	038 10	.23	172 76	150/250
86.51	unit H-1 top	25	unimodal	.55	323 07	.30	054 04	.15	172 82	323
86.52	lam? diamict	25	weak poly	.52	047 11	.32	317 00	.15	226 79	047
86.53	massive diamicton	25	weak bim	.56	140 01	.34	050 07	.10	241 83	175/090
86.54	massive diamicton	25	weak uni	.58	005 02	.30	096 23	.12	271 66	054
86.56	unit 3 mass.diamict	25	unimodal	.56	052 22	.31	321 03	.13	223 68	052
86.56	top unit 3	25	unimodal	.66	050 14	.29	146 21	.07	288 64	050

Appendix 3:- Grain size analysis

Below are listed the results of hydrometer and sieve analysis of samples collected. The section numbers match those given in Appendix 1, and it should be noted that some sections have more than one number (see Appendix 1). Sample number gives the alphabetic modifier attached to each sample (i.e. the full sample number would be, for example, 86.15.a or 19.6.3.a).

Section #	sample #	field description	sand %	silt %	clay %
16.6.1	a	laminated silt, overlying gravel	0.60	20.73	78.67
19.6.3	a	diamicton, massive, laminae of fine sand	25.60	29.10	45.30
20.6.1	a	finely laminated silt and clay, no stones	2.60	8.40	89.00
20.6.1	b	diamicton, massive below sample a	14.00	35.00	51.00
20.6.4	b	laminated clay (unit 6, 86.9)	0.50	9.80	89.70
20.6.4/86.9	c	sandy diamicton, massive (unit 1, 86.9)	26.00	35.80	38.20
86.9	a	unit 2, massive stone poor diamicton	30.60	32.03	37.37
86.9	b	unit 6, silt/clay couplets, rare stones	0.20	15.58	84.22
86.9	b.b	base of couplet	0.51	13.88	85.61
86.9	b.t	top of couplet	0.20	13.91	85.89
86.9	c	thick silt/ clay couplet, base of unit 7	0.20	11.91	87.89
86.9	d	upper 10 silt/ clay couplets, unit 7	0.40	14.75	84.85
86.9	e	massive buff silt, unit 27	0.20	35.50	64.30
21.6.1	a	basal 10 silt/ clay couplets (unit 2, 86.1.B)	0.40	29.77	69.83
21.6.1	b	lam. clay below buff silt (unit 47,86.1.B)	0.20	15.56	84.24
21.6.1	c	lower massive silt bed (unit 49, 86.1.B)	0.20	34.31	65.49
21.6.1	d	laminated clays, top of section (unit 60)	0.40	25.48	74.12
21.6.1/ 86.1	e	upper buff silt (unit 61)	0.60	41.26	58.14
86.1.A	a	unit 1, massive diamicton	21.60	43.35	35.05
86.1.A	b	unit 2, sandy, discontinuous diamicton	18.40	45.25	36.35
86.1.B	a	unit 2 silt/ clay couplets, rare stones,intraclast	0.80	40.53	58.67
86.1.B	b	#6 sandy discontinuous diamicton	28.00	35.00	37.00
86.1.B	c	# 7 silt/ clay couplets common intraclasts	3.00	26.18	70.82
86.1.B	d	#17 silt/ clay couplet common stones, rare int	5.80	20.60	73.60
86.1.B	e	#20 thick silt/ clay couplet no stones, intraclast	0.60	17.40	82.00
86.1.B	f	#26 silt/ clay couplets, few stones, intraclasts	1.40	16.50	82.10
86.1.B	g	#30 silt/ clay couplets few stones no intraclast	0.80	17.18	82.02
86.1.B	h	#35 2 thick couplets, rare stones, intraclasts	4.20	25.00	70.80
86.1.B	i	#41 massive silt rare stones	0.80	36.73	62.47
86.1.B	j	#42 silt/ clay couplets many stones, intraclasts	14.40	30.05	55.55
86.1.B	k	#47 silt/ clay couplet, intraclasts, no stones	0.80	12.59	86.61
86.1.B	l.49	#49, massive buff silt, no coarse clasts	0.00	36.29	63.71
86.1.B	l.52	#52 massive/ laminated clay no stones	0.00	19.22	80.78
86.1.B	m	#55 massive buff silt	0.20	20.14	79.66
86.1.B	n	#56, poorly laminated clay	0.02	17.18	82.80
24.6.3	a	laminated/ massive diamicton	27.80	31.50	40.70
24.6.3	b	as above	20.40	36.30	43.30
25.6.5 /86.15	a	massive diamicton unit A.0	34.80	29.80	35.40
86.15	a	unit A.1 silt rich stone poor diamicton	11.80	45.63	42.57
86.15	b	A.2, massive buff silts with stones	2.20	39.76	58.04

Section #	**sample** #	**field description**	**sand** %	**silt** %	**clay** %
86.15	c	A-3,silty diamicton, few coarse clasts	8.00	36.29	55.71
26.6.5	a	lens of sand within diamicton	64.20	22.50	13.30
26.6.5	b	diamicton, massive with lenses	15.60	36.30	48.10
26.6.5	c	banded diamicton	17.00	30.40	52.60
26.6.5	d	laminated clays (interbed with diamicton)	0.60	6.00	93.40
1.7.14	a	massive diamicton	24.40	30.83	44.77
4.7.1	b	massive diamicton/ shale bedrock	21.40	26.85	51.75
6.7.1	a	stony, sandy diamicton	50.20	27.47	22.33
7.7.5	a	massive diamicton	29.60	26.90	43.50
7.7.6	a	massive stone poor diamicton	19.60	34.80	45.60
7.7.7	a	laminated ? clay, slumping	6.60	31.40	62.00
10.7.1	a	laminated clay, no stones	0.40	7.37	92.23
10.7.1	b	massive/ stratified diamicton	9.60	36.90	53.50
10.7.5	a	laminated silt/ clay (unit 3, 86.51)	0.80	48.20	51.00
10.7.5/86.51	b	diamicton with sand stringers (unit H-1, 86.51)	12.00	38.50	49.50
86.51	a	base unit H-1, massive diamicton,	12.00	40.85	47.15
86.51	b.1	mid H-1, massive diamicton	10.00	38.68	51.32
86.51	b.2	duplicate analysis	10.40	40.47	49.13
86.51	c	top, H-1, stratified diamicton, laminae of silt	7.60	37.04	55.36
86.51	c.2	duplicate analysis	7.00	39.10	53.90
86.51	d	H-2, silt/ clay couplets, rare stones	4.20	47.24	48.56
86.51	e	H-3, silt couplet, no stones, intraclasts	1.00	60.20	38.80
86.51	et	top of couplet	0.20	12.73	77.69
86.51	eb	base of couplet	1.20	49.75	42.30
86.51	f	H-4, couplets, many clay intraclasts	1.40	36.98	61.62
86.51	g	H-6, silt/ clay couplets, rare stones	0.02	6.51	90.77
86.51	h	H-9, stratified diamicton, many intraclasts	8.20	10.33	81.47
86.51	i	H-10, diamicton, many intraclasts, stones	28.40	26.51	45.09
86.51	j	H-10, silt couplets, many stones, intraclasts	3.40	9.32	87.28
86.51	k	H-11, thick couplets, rare stones	0.60	14.28	85.12
11.7.1	a	stone poor massive diamicton	23.80	37.30	38.90
11.7.10	a	silty stone poor diamicton (colluvium?)	6.60	31.00	62.40
12.7.2	a	diamicton with clay laminae	16.20	30.10	53.70
17.7.3	a	clayey silts, laminated and X laminated	0.80	76.90	22.30
17.7.6	a	massive diamicton	25.80	70.20	4.00
17.7.6	b	sand/ silt lens within diamicton	2.40	76.00	21.60
18.7.2 /86.28	a	bedded clay with rare stones (unit1 86.28)	3.20	17.93	78.87
86.28.a	a	unit#1, silt with many intraclasts, few stones	3.20	17.53	79.27
86.28.a	b	#1, as above, from lens	2.60	18.30	79.10
86.28.a	c	# 3, clay interbed	0.20	24.41	75.39
86.28.b	a	clays, many intraclasts, few stones	2.00	12.08	85.92
86.28.b	b	buff silt, many stones	22.00	23.48	54.52
19.7.3	a	massive diamicton	22.80	37.63	39.57
20.7.5/86.31	b	laminated clay, no stones (unit 1, 86.31)	0.50	38.58	60.92
86.31	a	#1 silt/clay couplets, rare intraclasts, no stones	0.20	38.90	60.90
86.31	b	unit #2 massive clay and silt	0.80	26.18	73.02
22.7.7	a	diamicton, interstratified with sand	30.60	30.21	39.19
24.7.6	a	basal diamicton, unit 1, 86.17	21.20	34.14	44.66
24.7.6	b	laminated clay lens in diamicton,unit 9 86.17	1.60	27.02	71.38

Section #	**sample** #	**field description**	**sand** %	**silt** %	**clay** %
24.7.6	c	massive diamicton, lower unit 10, 86.17	23.00	32.22	44.78
24.7.6/86.17	d	massive diamicton unit BRII-8 86.17	23.20	45.29	31.51
86.17	a	unit BRII-1, diamicton with sand lenses	19.80	36.63	43.57
86.17	b	diamicton, interstrat. with sand, unit BRII-4	50.00	27.51	22.49
86.17	c	as above	64.40	23.94	11.66
86.17	d	BRII-6, diamicton	19.00	40.26	40.74
86.17	e	BRII-6, laminated clay couplets	1.20	53.54	45.26
86.17	f	BRII-7 massive diamicton, base	20.00	41.61	38.39
86.17	f.2	BRII-7, massive diamicton,top	19.00	45.20	35.80
86.17	g	BRII-8, massive diamicton	26.60	43.96	29.44
26.7.1	a	massive diamicton	20.40	33.43	46.17
26.7.1	b	laminated clay, few stones	3.80	18.83	77.37
27.7.1	a	diamicton	29.60	29.19	41.21
29.7.5	a	diamicton	31.00	27.64	41.36
29.7.7	a	diamicton	24.20	33.80	42.00
29.7.12	a	banded diamicton	17.40	35.33	47.27
29.7.14	a	l aminated clay, some stones	4.30	11.32	84.38
30.7.2	a	massive clay rich diamicton, few stones	6.80	23.03	70.17
30.7.6	a	massive diamicton	21.60	35.26	43.14
30.7.6	b	as above, lower unit	24.40	31.51	44.09
86.11	a	massive diamicton	31.20	51.39	17.41
86.12	a	massive diamicton	33.40	30.26	36.34
86.16/5.7.2	a	unit 1, diamicton, rare clay laminae	29.80	47.40	22.80
86.16	b	# 4 silt/ clay, common stones	12.20	23.86	63.94
86.16	c	#10, silt/ clay couplets, many stones	3.20	20.42	76.38
86.19/6.7.8	a	massive diamicton	29.80	47.42	22.78
86.20/5.7.8	a	massive diamicton	16.40	38.95	44.65
86.23	a.b	laminated sand, couplet base	24.00	55.33	20.67
86.23	a.t	clay, top of couplet	1.80	26.14	72.06
86.26/17.7.8	a	SA-1,stratifieddiamicton, base of graded bed	23.20	37.98	38.82
86.26	b	SA-1 top of graded bed	1.00	75.14	23.86
86.26	c	channel sample, top of unit SA-1	12.80	77.52	9.68
86.26	d	SA-2, stratified diamicton, lenses of sand	18.20	45.92	35.88
86.32/20.7.9	a	HC-1, massive diamicton	21.20	27.53	51.27
86.32	b	HC-3,lenses of diamicton	24.80	36.77	38.43
86.32	c	HC-4, laminated clay, many intraclasts	0.20	12.80	87.00
86.32	d	HC-5, thick silt/ clay couplets	5.60	31.10	63.30
86.40	a	massive diamicton	6.60	46.55	46.85
86.43	a	masive diamicton	20.20	56.09	23.71
86.45	a	massive diamicton	24.20	49.70	26.10
86.46/10.7.6	a	#1, strat. diamicton, silt laminae	6.80	39.21	53.99
86.46	b	#2.silt couplets, many intraclasts, stones	1.20	19.93	78.87
86.46	c	#3 thick couplets, no stones, intraclasts	0.02	3.98	96.00
86.46	d	#4 couplets, many intraclasts, some stones	0.60	6.01	93.39
86.46	e	#6, clay couplets, rare intraclasts	0.02	5.98	94.00
86.46	f	#7, couplets, common intraclasts	0.20	7.00	92.80
86.46	g	#8 thick couplets, intraclasts at base	0.40	12.06	87.54
86.48	a	diamicton with sand interbeds	13.80	37.16	49.04

Section #	**sample #**	**field description**	**sand %**	**silt %**	**clay %**
86.49	a	#1,intraclast conglomerate, sand matrix	52.00	17.87	30.13
86.49	b	#3, clay bed in laminated silt and sand	17.80	60.53	21.67
86.49	c	#4, massive diamicton	24.60	35.77	39.63
86.50	a	#1 massive clay, many intraclasts, stones	1.60	16.40	82.00
86.50	b	#5, laminated clay, many stones, intraclasts	6.60	12.76	80.64
86.50	c	#6, diamicton, abundant intraclasts	16.40	23.72	59.88
86.50	d	#7 laminated clay, many intraclasts, stones	2.00	11.76	86.24
86.50	e	#8 resistant buff clay, few stones	1.60	22.97	75.43
86.50	f.1	#10, top of couplet	0.80	11.20	88.00
86.50	f.2	#10, base of couplet	2.80	25.66	71.54
86.56/4.7.7	a	#3, base, massivediamicton	24.40	34.63	40.97
86.56	b	#3, top, massive diamicton	25.60	31.68	42.72
86.56	c	#4, couplets, few stones, many intraclasts	3.80	19.72	76.48
86.56	d	#6, couplets, many stones, intraclasts	3.60	15.30	81.10
86.56	e	#9, couplets, many intraclasts	1.60	7.12	91.28
86.56	e.2	duplicate	2.20	15.43	82.37
86.56	f	#14, massive to poorly laminated silt	3.00	35.42	61.58
86.56	g	#15, couplets, many stones	6.00	22.73	71.27
86.56	h	# 17, massive silt	1.40	30.58	68.02
86.56	i	#21, clay, poorly laminated/ massive	0.00	4.02	95.98
86.57	a	#1, diamicton, mainly intraclasts	15.00	25.90	59.10
86.57	b	#7, intraclast diamicton/ clay couplets	19.60	24.69	55.71

Appendix 4:- Clast lithology

This appendix lists the results of lithological analysis of clasts collected during the field study. The lithological classification is four-fold:-

1. Shield, including pink and red granites, gneisses and other high grade metamorphics

2. Quartzite; including quartzites and chert derived from the Cordillera and the Athabasca quartzite.

3. Carbonates; including Devonian carbonates from the margin of the Canadian shield, and dolomites and limestones from the Rocky Mountains

4. Local; sandstone, iron concretions, shale and coal derived from bedrock underlying the map area.

Diversity is simply the number of rock types identified in the sample.

Sample	sample size	shield %	quartzite %	carbonate %	local %	diversity
24.6.3 a	43	25.6	25.6	41.8	7.0	8
25.6.5 a	39	2.6	66.6	2.6	28.2	7
26.6.5	51	31.4	21.5	33.3	13.7	9
6.7.1	44	2.3	45.4	13.6	27.4[1]	11
7.7.5 a	49	2.1	18.4	0.0	79.6	8
19.7.3	78	14.1	65.4	11.5	9.0	8
86.02fab	55	7.3	7.3	12.7	72.7	9
86.06 fab	42	23.8	35.7	14.2	26.1	8
86.08	50	16.0	30.0	42.0	12.0	10
86.09 a	51	7.8	13.7	5.8	72.5	8
86.09 fab	51	7.7	17.9	7.7	66.7	7
86.10 fab	38	34.3	21.0	28.9	15.8	9
86.11 f ab	54	0.0	50.0	16.6	33.4	7
86.12 fab	46	2.2	47.8	4.3	45.7	5
86.13 fab	40	15.0	25.0	10.0	50.0	8
86.14 fab	41	21.9	22.0	53.7	2.4	8

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[1] Does not sum to 100% as 3 clasts of mica schist and slate were found which cannot be classified into any of the four catergories

Sample	sample size	shield %	quartzite %	carbonate %	local %	diversity
86.17, BRII-1	47	19.1	42.6	8.5	29.8	7
86.17 BRII-7	51	7.8	25.5	21.5	45.1	9
86.17 BRII-7	30	23.3	26.7	13.3	36.7	10
86.17 BRII-8	40	20.0	30.0	15.0	35.0	10
86.19 a	62	8.1	27.4	12.9	51.6	8
86.20 a	49	10.2	6.1	18.4	65.3	11
86.21 a	41	26.8	29.2	24.3	19.5	8
86.22 a	55	7.3	60.0	21.8	10.9	7
86.24 a	42	28.6	45.2	14.3	11.9	10
86.25 fab	62	22.6	30.6	33.9	12.9	12
86.26 SA-1	36	11.1	44.4	19.4	25.0	7
86.26SA-2	42	26.2	59.5	2.4	11.9	8
86.27 a	46	30.4	30.4	19.6	19.6	8
86.29 fabric	50	16.0	70.0	2.0	12.0	10
86.30 fab	49	18.4	47.0	26.5	8.1	10
86.32 HC-1	65	15.3	47.7	29.2	4.6	11
86.33 fab	47	25.5	36.2	27.6	10.6	9
86.34 fab	42	14.2	35.7	33.3	16.6	8
86.35 fab	42	9.5	42.9	35.7	11.9	9
86.41 fab	59	23.7	44.1	30.5	1.7	9
86.42 fab	66	18.2	25.7	33.3	22.7	9
86.43 a	79	3.8[2]	53.2	1.3	41.8	11
86.45 a	81	0.0	14.8	23.4	61.7	7
86.51 H-1	49	12.3	73.5	0.0	10.2	8
86.51H-1	28	14.3	21.4	21.4	42.9	7
86.51H-1	38	15.8	21.0	7.9	55.3	9
86.52 fab	41	9.8	26.8	12.2	51.2	6
86.53 fab	52	11.5	19.3	34.6	34.6	7
86.56 a	50	20.0	44.0	24.0	12.0	11
86.56 af	49	18.4	36.7	38.8	6.1	7

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[2] These clasts were grey granitic rocks which may have been derived from the Rocky Mountain Trench, but pink/ red granites were found at this locality

Appendix 5:- Atterberg limit results

This appendix lists determinations of the liquid limit and plastic limit from the Beaverlodge III section (86.1) and the Beaverlodge I section (86.56), by the methods outlined in Holtz and Kovacs (1981).

sample	material	liquid limit	plastic limit	plastic index	activity
86.1.A a	unit 1, massive diamicton	27.0	12.0	15.0	0.428
86.1.A b	unit 2, sandy, discontinuous diamicton	38.6	17.4	21.2	0.583
86.1.B a	unit 2 silt/ clay couplets, rare stones, intraclast	45.5	21.5	24.0	0.409
86.1.B b	#6 sandy discontinuous diamicton	34.5	19.9	14.6	0.395
86.1.B c	# 7 silt/ clay couplets common intraclasts	61.8	21.8	40.0	0.565
86.1.B d	#17 silt/ clay couplet common stones, rare int.	56.2	29.3	26.9	0.365
86.1.B e	#20 thick silt/ clay couplet no stones, intraclast	43.8	23.1	20.7	0.252
86.1.B f	#26 silt/ clay couplets, few stones, intraclasts	57.0	30.3	26.7	0.325
86.1.B g	#30 silt/ clay couplets few stones no intraclast	59.7	27.8	31.9	0.389
86.1.B h	#35 2 thick couplets, rare stones, intraclasts	59.8	26.8	33.0	0.466
86.1.B i	#41 massive silt rare stones	46.1	24.4	21.7	0.347
86.1.B j	#42 silt/ clay couplets many stones, intraclasts	45.5	20.1	25.4	0.457
86.1.B k	#47 silt/ clay couplet, intraclasts, no stones	85.6	34.6	51.0	0.589
86.1.B l1	#49, massive buff silt, no coarse clasts	45.2	26.4	18.8	0.295
86.1.B l2	#52 massive/ laminated clay no stones	66.5	30.1	36.4	0.451
86.1.B m	#55 massive buff silt	62.3	35.5	26.8	0.336
86.1.B n	#56, poorly laminated clay	73.9	39.2	34.7	0.419
86.56 a	#3, base, massivediamicton	34.0	19.6	14.4	0.351
86.56 b	#3, top, massive diamicton	44.1	18.4	25.7	0.602
86.56 c	#4, couplets, few stones, many intraclasts	53.2	28.8	24.4	0.319
86.56 d	#6, couplets, many stones, intraclasts	44.4	23.8	20.6	0.254
86.56 e	#9,couplets, many intraclasts	79.1	29.2	49.9	0.547
86.56 f	#14,massive to poorly laminated silt	39.4	20.9	18.5	0.300
86.56 g	#15, couplets, many stones	52.6	30.5	22.1	0.310
86.56 h	# 17, massive silt	45.0	23.4	21.6	0.318
86.56 i	#21, clay, poorly laminated to massive	83.7	32.2	51.5	0.537

Appendix 6:- Roundness and sphericity data

This appendix gives the roundness and sphericity estimates for clasts collected from stratigraphic unit C, diamicton. The mean values for total sample, and each lithology are presented for each sample. Each column gives the roundness (R), sphericity (S), and sample size (N).

Section	Total				shield			quartzite			carbonate				local
	R	S	N	R	S	N	R	S	N	R	S	N	R	S	N
86.02	.531	.454	22	.566	.466	3	.650	.475	4	.571	.471	7	.414	.414	7
86.06	.582	.485	33	.528	.414	7	.620	.493	15	.617	.517	6	.500	.520	5
86.08	.551	.449	49	.537	.400	8	.600	.457	14	.541	.468	22	.480	.420	5
86.09, comb	.522	.437	70	.485	.414	7	.722	.455	9	.545	.481	11	.481	.425	43
86.09 unit1	.528	.428	39	.566	.366	3	.716	.466	6	.550	.50	2	.482	.421	28
86.09 unit 2	.516	.448	31	.425	.450	4	.733	.433	3	.544	.477	9	.480	.433	15
86.10	.58	.504	25	.540	.500	10	.578	.533	9	.66	.50	5	.60	.50	1
86.11	.549	.528	53			0	.570	.537	27	.589	.533	9	.494	.512	17
86.12	.604	.512	51	.500	.500	1	.732	.614	22	.650	.550	2	.496	.423	26
86.13	.529	.457	28	.467	.383	6	.590	.500	10	.700	.550	4	.413	.412	8
86.14	.505	.481	42	.490	.570	10	.544	.422	9	.500	.464	22	.400	.500	1
86.15	.488	.475	45	.600	.700	1	.538	.514	21	.425	.418	16	.471	.457	7
86.17 comb	.541	.508	146	.514	.539	28	.595	.510	49	.526	.504	23	.506	.489	46
86.17 BRII-1	.539	.502	38	.522	.488	9	.566	.514	21	.550	.500	4	.425	.475	4
86.17.BRII-3	.506	.486	44	.475	.575	4	.610	.520	10	.480	.470	10	.475	.460	20
86.17.BRII-7	.488	.502	43	.460	.540	5	.577	.611	9	.490	.490	11	.450	.444	18
86.17.BRII-7	.576	.516	30	.442	.457	7	.688	.516	6	.675	.475	4	.569	.561	13
86.17.BRII-8	.551	.534	35	.587	.650	8	.591	.491	12	.480	.600	5	.510	.460	10
86.19	.542	.485	64	.480	.440	5	.600	.550	18	.550	.466	12	.512	.462	29
86.20	.484	.503	38	.500	.440	5	.700	.500	3	.489	.511	9	.448	.514	21
86.21	.532	.464	44	.382	.418	11	.671	.507	14	.509	.473	11	.525	.438	8
86.22	.559	.498	51	.517	.567	6	.603	.510	30	.509	.464	11	.425	.400	4
86.24	.575	.472	40	.457	.514	7	.604	.452	23	.60	.467	6	.575	.525	4
86.25	.538	.484	58	.500	.492	13	.616	.521	19	.500	.447	21	.500	.480	5
86.26 SA-1	.576	.445	29	.525	.375	4	.613	.473	15	.586	.414	7	.433	.467	3
86.26 SA-2	.624	.452	42	.527	.391	11	.689	.489	27	.400	.300	1	.467	.400	3
86.27	.543	.498	42	.500	.477	13	.586	.500	14	.544	.522	9	.533	.500	6
86.29	.614	.467	51	.486	.429	7	.676	.486	37	.500	.500	1	.400	.383	6
86.30	.581	.474	47	.537	.450	8	.605	.495	20	.592	.443	14	.520	.520	5
86.32 HC-1	.551	.567	57	N/A	N/A	10	N/A	N/A	33	N/A	N/A	19	N/A	N/A	4
86.33	.519	.502	47	.516	.508	12	.589	.489	18	.483	.508	12	.36	.520	5

Section	Total			shield			quartzite			carbonate			local		
	R	S	N	R	S	N	R	S	N	R	S	N	R	S	N
86.34	.530	.457	37	.467	.517	6	.543	.393	14	.561	.477	13	.475	.525	4
86.35	.542	.503	40	.550	.625	4	.547	.463	19	.535	.507	14	.533	.567	3
86.41	.527	.495	59	.500	.436	14	.572	.548	25	.483	.467	18	.550	.500	2
86.42	.542	.470	69	.475	.433	12	.625	.456	16	.512	.484	25	.556	.488	16
86.43	.583	.506	102	.525	.575	4	.660	.529	52	.600	.500	1	.500	.473	45
86.45	.548	.466	92	N/A		0	.608	.523	13	.484	.474	19	.555	.452	60
86.51 comb	.578	.520	118	.650	.525	16	.644	.563	49	.560	.530	10	.481	.467	43
86.51 base H-1	.644	.540	50	.716	.450	6	.651	.567	37	N/A		0	.542	.471	7
86.51 mid, H-1	.530	.523	30	.525	.475	4	.583	.600	6	.485	.500	7	.530	.515	13
86.51duplicate	.523	.476	30	.483	.516	6	.560	.500	5	.510	.470	10	.530	.440	10
86.51 top H-1	.531	.492	38	.666	.633	6	.666	.500	6	.766	.600	3	.434	.439	23
86.52	.531	.487	38	.500	.500	4	.622	.478	9	.560	.580	5	.490	.465	20
86.53	.526	.502	58	.433	.433	6	.658	.583	12	.504	.491	22	.494	.483	18
86.56 b unit 1	.563	.487	99	.523	.429	17	.612	.542	40	.506	.430	30	.566	.466	6
86.56 mid unit 1	.595	.538	50	.550	.487	8	.631	.577	22	.572	.500	11	.466	.400	3
86.56 top unit 1	.530	.436	49	.500	.377	9	.588	.500	18	.468	.389	19	.666	.533	3